ELEMENTARY PRINCIPLES OF
C A R P E N T R Y

CHIEFLY COMPOSED FROM THE STANDARD WORK OF

THOMAS TREDGOLD, C.E.

WITH ADDITIONS, ALTERATIONS, AND CORRECTIONS

AND A TREATISE ON

J O I N E R Y

CONTAINING

A DETAILED ACCOUNT of the VARIOUS OPERATIONS of the JOINER

BY E. WYNDHAM TARN, M.A.

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ELEMENTARY PRINCIPLES

OF

CARPENTRY.

CHAPTER I.

ON THE PROPERTIES, PRESERVATION, AND STRUCTURE OF TIMBER.

SECTION I.—On the Nature and Properties of Timber.

1. TIMBER being the material out of which all the works of the carpenter and joiner are executed, it becomes of great importance to those artizans that they should have some acquaintance with the mode of growth, nature, causes of decay, and other peculiarities of the various kinds of wood on which they have to employ their skill, in order that they may be able to turn their materials to the best account.

Wood is that substance which forms the principal part of the roots, trunks, and branches of trees and shrubs. The woods of different trees differ much in strength, hardness, durability, and beauty; and, consequently, in their fitness for the various purposes to which they are applied. The wood which is felled and seasoned for the purpose of building is called *timber*, from the Saxon word *timbrian*, signifying to build; and in stating the properties of woods, we shall consider those only which are fit for timber, or for building purposes generally

2. Growth of Trees.—Most of the timbers are derived from the class of trees which botanists denominate *Exogens*, a term signifying outward growers, from the fact of the new wood being added each year to the outside of that previously formed. All the timber trees which grow in temperate and cold climates, as well as many found in the tropics, belong to the class of Exogens. The mode of growth may be briefly described as follows:—The first year's growth of the plant consists of a stem, of which the centre is a soft substance called the *pith*, and is surrounded by a thin coating of *wood*, over which is the *bark*. In the second year the inner part of the bark separates from the wood, and sap forms between the wood and the bark, the new sap-wood being connected with the pith by means of the medullary rays, which are cross passages extending from the pith to the outside, and by which the secretions pass horizontally from outside to the centre. The chief use of the root is to absorb juices from the soil and convey them to the woody fibres immediately surrounding the pith, by which they are carried upwards and dispersed through all the branches to the remotest leaves, by means of which much of the water contained in the fluid is evaporated, and a complete change therein effected. The fluid descends from the leaves through a series of tubes in the inner part of the bark, and is deposited so as to form the new wood, bark, &c. The pith connects the root with the leaf-buds, to which it conveys nourishment; it is at first green, and filled with fluid, but loses its colour as it dries up and the tree gets old. This is the first part that decays in the live tree; and many trees which appear sound on the outside will be found when cut up to have decayed at the centre or pith; it also shows itself in the dead knots frequently met with in certain

kinds of wood. The cellular mass of the stem is pressed into plates of various thicknesses by the wedges of wood which are formed within it, so that when a transverse section is made of the stem, these plates appear as a number of lines radiating from the centre, which have received the name of *medullary rays*. The medullary sheath consists of spiral vessels surrounding the pith, projections of which pass through it into the medullary rays, and by means of this sheath oxygen is conveyed to the leaves, being obtained by the decomposition of water or of carbonic acid. Surrounding this medullary sheath is the *wood*, properly so called, and consists of concentric layers formed by successive deposits, year after year, of the nutriment which descends from the leaves. In countries which have a winter and summer, each layer of wood is the produce of a single year's growth ; the secretions are found most abundant in the oldest layers, and when these become filled up they cease to perform any vital function, and form what is termed *heart-wood*. The bark which covers and protects the newly formed wood is composed of several concentric layers, and is increased by additions to its inner layers, so as to allow for the gradual distension of the wood beneath : the outer bark does not increase, but splits off, and a new one takes its place. The bark serves the double purpose of being a protection to the new wood and also a filter through which the descending juices pass. The circulation of the sap will continue after the *outer* bark has been removed ; but if the stem is cut entirely through the inner bark, the descent of the sap will be stopped, and the tree will soon die.

If the stem or trunk of a tree is cut across, the wood is found to be made up of numerous concentric layers or rings, very distinct in some trees, but less so in

others. One of these layers is commonly formed every year in temperate or cold climates, consequently their number corresponds nearly with the age of the tree. In tropical climates, however, the growth is more rapid, and more than one ring may be formed in each year. Each layer consists, in general, of two parts—the one solid, hard, heavy, and dark-coloured; the other of a lighter colour, porous and soft, which renders the lines of separation between the annual layers distinct. Scarcely any two layers of the same tree are precisely alike, either in the proportion of the hard part, or in the thickness of the layers, as the layers vary in thickness according to the degree of vegetation which took place in the years of their formation; and also in the same tree they vary in thickness, either according to the situation of the principal roots, or the aspect; the annual layers being always thicker on that side of the tree which has been favourable to the growth of the roots, or that which has had the advantage of a good aspect.

The sap-wood is softer, and generally lighter coloured, than the heart-wood, and contains a considerable portion of vegetable matter, which partakes of the nature of the sap, and which descends through it. It is found to decay rapidly, and is also very subject to worms. The reason is obvious, for it contains the food which they live upon, the most of which is absorbed or evaporated from the heart wood.

The proportion of sap-wood in different trees varies very much: Spanish chestnut has a very small proportion of sap-wood, oak has more, and fir a still larger proportion than oak; but the proportions vary according to the situation and soil. Three specimens of a medium quality gave the following:—

Chestnut, whole age 58 years, 15½ inches diameter, 7 years' sap-wood, ⅜ inch thick.
Oak, whole age 65 years, 17 inches diameter, 17 years' sap-wood, 1¼ inch thick.
Scotch fir, 24 inches diameter, sap-wood 2½ inches thick.

Therefore, if the diameter be unity, or 1, that part of it which is sap-wood will be, in the chestnut, 0·1; in the oak, 0·294; and in the Scotch fir, 0·416. The Scotch fir was the produce of the Mar Forest.

3. The Life of Trees, like that of men, has been commonly divided into three stages—infancy, maturity, and old age. In the first, the tree increases from day to day; in the second, it maintains itself without sensible gain or loss; but in the third, it declines. These stages vary in every species, according to the soil, the aspect, the climate, or the nature of the individual plant; oak and chestnut trees decay sooner in a moist soil than in a dry and sandy one, and their timber is less firm; the sap vessels being expanded with moisture without the necessary quantity of nourishing matter, the general texture becomes necessarily less firm. Such wood splits easily, and is very liable to shrink and swell with the changes of the weather. Trees of the same kind arrive at the greatest age in that climate which is best adapted to their nature. The common oak, the fir, and the birch thrive best towards the northern, the ash and the olive tree thrive best towards the southern, parts of Europe.

The decline of trees appears to be caused by the decay of the heart-wood. In trees that have not arrived at maturity, the hardness and solidity of the wood are greatest at the heart, and decrease towards the sap-wood; but in the mature or perfect tree the heart-wood is nearly uniform; while that of a tree on the decline is softer at the centre than it is next the sap-wood.

4. Felling Timber should take place in the vigour

and perfection of the trees. When a tree is felled too soon, the greater part of it is sap-wood, and in a young tree even the heart-wood has not acquired its proper degree of hardness; indeed the whole tree must partake so much of the nature of sap-wood, that it cannot be expected to be durable. And when a tree is not felled till it be on the decline, the wood is brittle and devoid of elasticity, tainted, discoloured, and soon decays. But in trees that have arrived at a mature age, the proportion of sap-wood is small, and the heart-wood is nearly uniform, and is hard, compact, and durable. It is true the proper age for each species has not been satisfactorily determined; but it is a point where great accuracy is not necessary; for half a dozen years in the age of a tree will not make much difference, provided it be not cut too soon. It is cutting trees before they have arrived at maturity that should be guarded against; and as it is most likely to happen from interested motives, it is the more necessary to caution the carpenter in this respect. Trees increase slowly in size after they arrive at a certain age, therefore it is the interest of the timber grower to fell them before they arrive at maturity: because it is his object to obtain the greatest possible quantity of timber, without regard to the quality. But when the carpenter is sensible of the inferior quality of young timber in respect to duration, it is his province to check this growing evil, by giving a better price for timber that has acquired its proper degree of density and hardness.

The period generally allowed for an oak tree to arrive at maturity is 100 years, and the average quantity of timber produced by a tree of that age is about 1½ loads, or 75 cubic feet. In some instances oak trees arrive at maturity in a less time than 100 years,

and in others not till after that period; as a rule, its age should never exceed 200 years, nor should it be felled at a less age than 60. It is much to be regretted, that in districts where the oak flourishes it is seldom suffered to attain a mature age; being often cut before the trees will produce 50 feet of timber each. The ash, larch, and elm should be cut when the trees are between 50 and 100 years old; and between 30 and 50 is a proper age for poplars. The Norway spruce and Scotch pine are generally cut when between 70 and 100 years old in Norway.

5. SEASON FOR FELLING.—In order that timber may be durable, it is also necessary to attend to the proper season of the year for felling. But on this point there is much difference of opinion, and the question is only to be decided by attending to the state of trees at different seasons of the year. The best period for felling timber is undoubtedly that in which it is most free from extraneous vegetable matter; or such matter as is intended to be expended in forming leaves and buds, which is in a more fluid state, and of a more saccharine and fermentable nature than the proper juices, or such as form the wood. A tree deposits in the sap-wood a portion of matter to be dissolved by the descending sap, and at the period when the leaves are putting forth, the wood must be filled with matter in a state ready for germination; consequently the timber cut at that period must be easily acted upon by heat and moisture, and subject to rapid decay, or to be destroyed by worms. Of all periods of the year the spring must be the worst, because the tree then contains the greatest quantity of matter in a state fit for germination.

On the other hand, the best time for felling timber is in midwinter; as at that time the vegetative powers

are at rest, although in some kinds of trees a little after midsummer appears to be decidedly the best time for felling. Alder felled at that time is found to be much more durable; and beech, when cut in the middle of summer, is better and less liable to be worm-eaten; particularly if a gash be cut to let out the sap some time before felling. About Naples, and in other parts of Italy, oaks have been felled in summer, and are said to have been very durable. And as summer felling is an advantage in some species, it seems reasonable to conclude that it will be so in all.

6. Barking Trees.—In oak trees the bark is too valuable to be lost; and as the best period for the timber is the worst for the bark, an ingenious method has been long partially practised, which not only secures the bark at the best season, but also materially improves the timber. This method consists in taking the bark off the standing tree early in the spring, and not felling it till after the new foliage has put forth and died. For by the production of new buds the fermentable matter is expended, and the sap-wood becomes nearly as hard and durable as the heart-wood, both being less liable to decay and to be destroyed by worms. The wood is materially improved by this method of barking the trees standing in the spring, and felling them about the end of October. Where it is essential to give durability to the sap-wood of oak, the trees should be barked in the spring, and felled in the ensuing winter; also winter-felled heart-wood is less affected by moisture, and likely to be the best and most durable.

When the bark of a tree is not of sufficient value to defray the expense of stripping, the timber should be felled during the months of December, January, or February, in the winter, or during the month of July in the summer. Winter felling is better, chiefly in

consequence of the timber being less liable to split or twist in seasoning, from the drying being more gradual when it is cut at that time of the year. The advantage of slow drying may, however, be easily given at any season; and it certainly is a great advantage in this early stage of seasoning. According to Vitruvius, the proper time for felling is between October and February; and he directs that the trees should be cut to the pith, and then suffered to remain till the sap be drained out. The effusion of the sap prevents the decay of the timber; and when it is all drained out, and the wood becomes dry, the trees are to be cut down, when the wood will be excellent for use. A similar effect might be produced by placing the timber on its end as soon as it is felled, and it would no doubt compensate for the extra expense by its durability in use.

Section II.—Seasoning Timber.

7. Treatment of Timber.—When timber is felled, the sooner it is removed from the forest the better: it should be removed to a dry situation, and placed so that the air may circulate freely round each piece, but it should not be exposed to the sun and wind. Squared timber does not rift or split so much as that which is round; and where the size of the trees will allow of it, it is better to quarter them, after a period of very slow drying in the whole tree. When beams are to be used the full size of the tree, it would be a good preservative against splitting to bore them through from end to end, as is done in a water-pipe. It is irregular drying which causes timber to split; and this method would assist in drying the internal part of the beam, without losing much of its strength; at the same time it would lighten it considerably. It is a great advan-

tage to set the timber upright, with the lower end raised a little from the ground; but as this cannot always be done, the timber-yards should be well drained, and kept as dry as possible. Paved yards are to be preferred, and the paving should have a considerable fall, to prevent water standing. If the paving were laid with ashes it would be better; those from a forge or foundry would be excellent: even an unpaved yard would be improved by a coat of ashes, to prevent anything growing among the timber.

If timber can be kept some time in a dry situation before it is cut into scantlings, it is less subject to warp and twist in drying; but during the time it is kept in the tree or log it should be carefully piled, so as to leave space for a free circulation of air between each piece, and also between the timbers and paving or ground. In some yards the timber has been laid upon cast-iron bearers, instead of being laid upon refuse pieces of wood, as the refuse wood is often half rotten, and must in some degree contribute to infect the sound timber. Timber is too often suffered to lie half buried in the ground, or grown over with weeds, till it is covered with fungus, and impregnated with the seeds of decay before it is brought into use.

When it is necessary to convert the timber into smaller scantlings, it still requires attention; as the better it is seasoned, when brought into work, the better the work will stand: it will also be more durable. Such scantlings will dry soonest in an upright position, and the upper end dries more rapidly than the lower one. But whether the pieces of timber be piled on the end, or laid horizontally, a free space should be left round each piece, and the situation should be dry and airy; yet not exposed to the direct rays of the sun, nor to a strong current of air. If the

scantlings be laid horizontally, short blocks should be put between them, which will preserve them from becoming mouldy, and will contribute much towards rendering the sappy parts more durable.

Gradual drying, where the time can be allowed for it in the natural process, is the most certain means of giving durability to timber, by fixing those parts of it which are most liable to be acted upon by heat and moisture. It is well known to chemists that slow drying will render many bodies less easy to dissolve; while rapid drying, on the contrary, renders the same bodies more soluble: besides, all wood in drying loses a portion of its carbon, and the more in proportion as the temperature is higher. There is in wood that has been properly seasoned a toughness and elasticity which is not to be found in rapidly dried wood. This is an evident proof that firm cohesion does not take place when the moisture is dissipated in a high heat. Also, seasoning by heat alone produces a hard crust on the surface, which will scarcely permit the moisture to evaporate from the internal part, and is very injurious to the wood.

For the general purposes of carpentry, timber should not be used in less than two years after it is felled; and this is the least time that ought to be allowed for seasoning. For joiners' work it requires four years, unless other methods be used; but for carpentry natural seasoning should have the preference, unless the pressure of the air be removed. The quantity of matter which ought to be evaporated from green oak is about one-third or two-fifths of its weight; the proportion, however, will vary according to the age and quality of the timber and the nature of the soil that produced it.

8. Water Seasoning.—On account of the time required to season timber in the natural way, various

methods have been tried to effect the same purpose in a shorter time. Perhaps the best of these is to immerse the timber in water as soon as it is cut down; and after it has remained about a fortnight in water, but not more, to take it out, and dry it in an airy situation. Timber for the joiner's use is best put in water for some time, and afterwards dried, as it renders the timber less liable to warp and crack in drying; but where strength is required it ought not to be put in water. Timber which has remained some time in fresh water loses more of its weight in drying than that which is dried under cover.

Timber that has been cut when the tree was full of sap, and particularly when that sap is of a saccharine nature, must be materially benefited by steeping in water; because it will undoubtedly remove the greater part of the fermentable matter: the sap-wood of oak is materially improved by it, being much less subject to worm-eat; and also the tender woods, such as alder and the like, are less subject to the worm when water-seasoned. Beech is said to be much benefited by immersion; and green elm, if plunged four or five days in water (especially salt water), obtains an admirable seasoning.

When timber is put in water it must be sunk so as to be completely under water, as nothing is more destructive than partial immersion. Salt water is considered best for ship-timber; but for timber to be employed in the construction of dwelling-houses fresh water is better.

9. Steaming or Boiling timber impairs its strength and elasticity, but it gives another property, which for some purposes is still more desirable than strength; for boiled or steamed timber shrinks less and stands better than that which is naturally seasoned. Therefore it may often be useful to season timber in this

manner where joiners' work is to be executed in oak of British growth, as without this precaution it requires a long time to season it so as to be fit for such purposes. The timber should not remain long in water or steam; four hours will in general be quite sufficient; and after boiling or steaming the drying goes on very rapidly, but it is well not to hasten the drying too much. Steamed wood dries sooner than that which is boiled.

How far steaming or boiling affects the durability of timber has not been satisfactorily ascertained: but it is said that the planks of a ship, near the bows, which are bent by steaming, have never been observed to be affected with the dry rot. The changes produced by boiling are not very favourable to the opinion that it adds to the durability of timber. For when a piece of dry wood was immersed in boiling water, and afterwards dried in a stove, it not only lost the water it had imbibed, but also a part of its substance; and when the experiment was repeated with the same piece of wood, it lost more of its substance the second time than it did the first. The same thing takes place in green wood; and tender woods, or those of a middling quality, are more altered by these operations than hard woods, or those of a good quality. Steeping long in cold water produces similar effects; but box, oak, and ash lose more weight by this process than mahogany, walnut, or deal. Both cold and hot water have therefore to a certain extent the power of dissolving the woody fibre.

10. Smoke-drying has from very ancient times been found to contribute much to the hardness and durability of wood. But this method can only be effectually applied on a very small scale; yet sometimes, for particular purposes, it may be useful to season in the smoke. As a substitute for the smoke of an open chimney, fern,

furze, straw, or shavings can be burnt under the timber, which would destroy any seeds of fungi, or worms, and so embitter the external surface as to prevent any further ill effect from either. It would be easy to contrive the means of smoke-drying for the use of a manufactory where much seasoned wood was used.

SCORCHING must do timber much harm when it is done hastily, so as to cause rents and cracks in it; as these become receptacles for moisture, and consequently must be the cause of rapid decay.

CHARRING the surface is only useful in as far as it destroys and prevents infection; and it should be applied only to timber already seasoned: for when it is applied to green timber, it only closes up the pores at the surface, so that the internal sap and moisture cannot evaporate. In that kind of decay which arises from the constant evaporation of moisture, charring the surface produces no effect, but as a preventive of infection by the dry rot, and of the worm in timber, it appears to be very beneficial, and will no doubt be assisted by impregnating the timber with the bitter particles of smoke.

11. WEIGHT OF TIMBER IN DIFFERENT STATES.—As a suitable introduction to some remarks on seasoning, we subjoin the following table of the weight of timber in different states, from experiments made by Duhamel on woods of French growth:—

Kind of Wood.	Weight of a cubic foot green.	Weight of a cub. foot one year afterwards.
Oak	78·25	68·3
Elm	57·14	47·5
Poplar	49·68	30·69
Walnut	54·43	44·08
Lime	45·2	27·96
Beech	56·25	43·95
White pine . . .	53·73	43·93
Norway pine, dry . .	—	36·75

The weight of a cubic foot of green oak varies from 62·5 to 66 pounds; of a cubic foot of seasoned oak, from 53·5 to 58 pounds; and a cubic foot of very dry oak, from 44·6 to 47·3 pounds. The timber of very old trees is often much lighter than this; some specimens from old trees did not exceed 38·5 pounds per cubic foot when dry. The loss of weight in oak has been found to amount to 40 per cent. in some cases. When the specific gravity is very low it may be safely concluded that it is the wood of an old tree, and that it will be brittle and deficient both in strength and toughness.

The following tables are compiled from experiments made by Mr. Couch at Plymouth Dockyard:—

Kind of Wood.	Weight when felled of a cub. foot.	Weight seasoned of a cubic foot.	Shrinkage in bulk by seasoning.
	Pounds.	Pounds.	
Oak (butt-end) . .	69	47½	$\frac{1}{32}$
Elm	58½	36½	$\frac{1}{26}$
	Weight of a cubic foot when first imported.		
Riga masts . . .	42	40	$\frac{1}{72}$
Pitch pine, American .	47	46¼	$\frac{1}{40}$
Yellow pine, ditto . .	42½	28¾	$\frac{1}{144}$
Spruce pine, ditto . .	33	32¾	$\frac{1}{113}$

Kind of Wood.	Weight of a cubic foot when green.	Weight of a cubic foot dry.	Loss per cent.
	Pounds.	Pounds.	
Oak sap-wood . .	67·0	47·07	29·8
Spanish chestnut . .	54·68	37·91	30·6
Larch	42·06	30·99	26·0
Walnut	57·5	38·5	33·0
Acacia	51·25	46·76	9·0

The following table gives the results obtained by Wiebeking's experiments:—

Kind of Wood.	Weight of a cubic foot fifteen days after the wood was felled.	Weight of a cubic foot after three months' exposure to the air.	Weight of a cubic foot when dry.
	Pounds.	Pounds.	Pounds.
Oak	68·74	56·18	39·27 to 39·58
Larch	63·63	51·08	38·31
Pine (pinus sylvestris).	51·08	38·31	26·817
Pinaster	52·35	33·2	25·54
Fir (pinus picea) .	33·2	29·37	25·22 to 25·54

Wood, when it is cut into small pieces, very soon acquires its utmost degree of dryness. The sap-wood of oak loses more weight in drying than the heart-wood, in the proportion of 10 to 7; and the sap-wood of larch loses two-fifths of its weight in drying.

Timber is used in two states; that is, when it is *dry*, and when it is only *seasoned*. The term seasoned, however, is not very accurately defined; timber has undergone what is termed a proper seasoning for common uses when it has lost about one-fifth of the weight that it had when felled.

Timber loses about one-third of its weight in becoming dry; and such a degree of dryness being sufficient for the joiner's purpose, timber may be considered *dry* when it has lost one-third of its weight.

Thus the terms *dry* and *seasoned* will have a more certain meaning: and when drying is carried to its greatest degree, the timber may be called *perfectly dry*, to distinguish it from that degree of dryness which renders it fit for framing and joiners' work.

The long time which large pieces require to season should render their use less frequent, without a proper time can be allowed. In the following table is given the times of drying and seasoning pieces of different sizes in the open air, which shows at once the time necessary to bring different scantlings to the same

degree of dryness; the time under cover is shorter in the proportion of 5 to 7:—

Length in ft.	Breadth in ins.	Thickness in ins.	Time of seasoning in months.	Time of drying in months.
10	6	6	11	29
10	8	8	15	39
12	10	10	18	48
12	12	12	22	57
12	14	14	25	66
12	16	16	29	76
18	18	18	32	86
20	20	20	36	96

Section III.—Decay and Preservation of Timber.

12. Effects of Dryness and Moisture.—Timber, when properly seasoned, is strong, tough, and elastic; but it does not long retain those properties in any state or situation. Timber is often employed in situations where it is continually dry, where it is constantly wet, where it is alternately wet and dry, or where it is exposed to heat and continued moisture. The effect of each of these states is the next object of attention.

Timber that is *constantly dry*, or affected only by the small quantity of moisture it absorbs from the air in damp weather, has been known to last for seven or eight hundred years; but even in this state, time produces a sensible alteration in its properties; for it is found to lose its elastic and coherent powers gradually, and to become brittle. Hence it is unfit to sustain the action of variable loads, though in a state of rest it may endure for an immense length of time.

Wood in its natural state is a very compound substance; a certain portion of its constituents is soluble in water; another part may be extracted by alcohol; and the part remaining, after being treated with alcohol, is the pure woody fibre, or lignin of chemists. After

water has extracted all that is soluble by it from timber, it is obvious that while the timber continues immersed in water it may remain unchanged for an indefinite period; but if it be taken out and dried, it is found to be brittle and effete; or, to use the workman's expression, "its nature is gone;" and it dries, splits, becomes light, and soon impairs. But though oak timber taken from bogs is always found to be brittle and in a state of decay, fir from the same bog is often, if not always, in a much sounder state.

When timber is exposed to the action of *alternate dryness and moisture* it soon decays. It has been already noticed, that repeated steeping and drying removes a sensible portion of the wood at each operation (8, 9); and it is evident that at each drying a new portion of soluble matter is formed, which either did not before exist, or which is rendered soluble by a change in its principles. This effect may be observed in weather-boarding, fencing, and in any situation where wood is constantly exposed to the vicissitudes of the weather. When the timber has been thoroughly seasoned, painting or any other kind of coating that is capable of resisting moisture is the best means of preserving it from this kind of decay (26).

13. Effects of Continued Moisture with Heat.—Wood, in common with other vegetable products, when exposed to a certain degree of moisture, and at a temperature not much under 45° Fahr., nor too high to evaporate suddenly all the moisture, gradually decomposes. This decomposition is called putrefaction by chemical writers, but is called the *rot* in common language. It proceeds with most rapidity in the open air, but the contact of air is not absolutely necessary. Water is in all cases essential to the process; indeed it is a principal agent in all processes of decomposition.

As the rot goes on, certain gaseous matters are given out; chiefly carbonic acid gas and hydrogen gas. Pure woody fibre alone undergoes this change slowly, but its texture is soon broken down, and it is easily resolved into new elements when mixed with substances more liable to change. Any process that tends to abstract carbonaceous matter from it must bring it nearer in composition to the soluble principles, and this is done by fermentation. Hence it is that the sap-wood is of a more perishable nature than the heart-wood, for the sap-wood abounds more in saccharine and fermentable principles, and consequently sooner decomposes

Quicklime, when assisted by moisture, has a powerful effect in hastening the decomposition of wood, in consequence of its abstracting carbon. Mild lime (carbonate of lime) has not this effect. But mortar requires a considerable time to bring it to the state of mild lime; therefore, bedding timber in mortar, or building it in walls where it will long remain in a damp state in contact with mortar, is very injurious, and often the cause of rapid decay. Wood in a perfectly dry state does not appear to be injured by dry lime: of this we have examples in plastering-laths, which are generally found sound and good in places where they have been dry. Lime also protects wood from worms.

Volatile and fixed oils, resins, and wax, are equally as susceptible of decay as woody fibre under the same circumstances; hence we see the impropriety of attempting to protect wood in any situation where the coat of paint, &c., cannot be renewed from time to time: and also, that woods abounding in resinous matter cannot be more durable than others.

Decay sometimes commences in the growing tree; for when it has stood beyond a certain age, decay at

the heart has generally made some progress (3). This has often been observed in large girders of yellow fir, which have appeared sound on the outside, but by removing some of the binding joists have been found completely rotten at the heart. It is on this account that the practice of sawing and bolting girders is recommended.

It is usual to divide the rot into two kinds, the *wet rot* and the *dry rot;* the main distinction between them being, that in the one the gaseous products are evaporated, and in the other the greater part of them form into a new combination which is a species of fungus. Both, in a chemical sense, are produced by precisely the same causes, with this exception, that a free evaporation determines it to be the wet rot; a confined place, or imperfect evaporation, renders it the dry rot, as timber must be decomposed in becoming the food of a plant; it is evidently the same with the putrefaction of chemists with different products. It is said that the decay of a post placed in the ground, or in water, is an example of the wet rot; and it is assumed that the parts undergoing the process of decay are alternately wet and dry; but the fact is, they are constantly supplied with that degree of dampness which is essential to putrefaction. For timber being composed longitudinally of an assemblage of pipes or tubes, it is only necessary that one end of a log of wood should be placed in a damp or wet situation, to occasion the moisture to be conveyed to the opposite end by capillary attraction. Prevent a free change of atmospheric air, and a post so circumstanced, it is well known, would be affected with the dry rot.

When only the external part of a beam has been seasoned, and the sap has never been evaporated from the internal part, the rot will be an internal disease;

and where an internal decay of this kind is found, it proves that the timber has never been properly seasoned.

14. Fungus on Rotten Wood.—In the first stages of rottenness the timber swells and changes colour, is often covered with mucor or mouldiness, and emits a musty smell. Where the rottenness is internal, or the timber is in a confined place, a new substance is formed between the fibres, of a spongy consistency, resembling the external coat of a mushroom: and the substance itself has been ascertained to belong to the order Fungi of the Cryptogamia class of plants. When the fungus first appears on the sides and ends of timbers, it covers the surface with a fine white and delicate vegetation, called by shipwrights a mildew. These fine shoots afterwards collect together, and the appearance then may be compared to hoar-frost, and increases rapidly, assuming gradually a more compact form, like the external coat of a mushroom, but spreads alike over wood, brickwork, stone, and plastering, in the form of leaves, being larger or smaller most probably in proportion to the nutriment the wood affords. The colours of the fungus are various: sometimes white, greyish white, with violet; often yellowish brown, or a deep shade of fine rich brown. In the more advanced stages of rottenness the woody fibres contract lengthwise, and show many deep fissures across the fibres, similar to a piece of wood scorched by the fire. The woody fibres appear to retain their natural form, but easily crumble into a fine powder. In oak this powder is of a fine snuff-brown colour. The fungus, when it spreads upon the surface of the wood, often becomes of a considerable size, sometimes spreading over the adjoining walls, and ascending to a considerable height.

15. Timbers most liable to Rot.—In timber of the same kind, that of the most sappy and rapidly grown

trees is the most subject to decay. The wood of trees from the close forests of Germany or America is more subject to it than that of trees grown in more open situations; and it is remarked that the timber brought from America in the heated hold of a ship is invariably covered over, on being landed, with a complete coating of fungus. Consequently, the timber must be infected with the seeds of decay before it is brought into use. Also the custom of floating timber in docks and rivers injures it very much: it would be better to sink it completely under water, as to half immerse in water is the worst situation it can be placed in. Though moisture be essential to the progress of decay, absolute wetness will prevent it, especially at a low temperature. In ships this has been particularly remarked, for that part of the hold of a ship which is constantly washed by the bilge-water is never affected by dry rot. Neither is that side of the planking of a ship's bottom which is next the water found in a state of decay, even when the inside is quite rotten, unless the rot has penetrated quite through from the inside.

16. WARMTH AND MOISTURE are the most active causes of decay; and provided the necessary degree of moisture be present, the higher the heat the more rapid is its progress. In warm cellars, or in any close confined situations where the air is filled with vapour without a current to change it, the rot proceeds with astonishing rapidity, and the timber-work is destroyed in a very short time. The bread-rooms of ships, behind the skirtings and under the wooden floors or the basement stories of houses, particularly in kitchens or other rooms where there are constant fires, and in general in every place where wood is exposed to warmth and damp air, the dry rot will soon make its appearance. All kinds of stoves are sure to increase the

disease, if moisture be present. The effect of heat is also evident from the rapid decay of ships in hot climates. And the warm moisture given out by particular cargoes is also very destructive, such as cargoes of hemp, pepper, and cotton.

17. Building Timber into New Walls is often a cause of decay, as the lime and damp brickwork are active agents in producing putrefaction, particularly where the scrapings of roads are used instead of sand for mortar. Hence it is that bond-timbers, wall-plates, and the ends of girders, joists, and lintels are so frequently found in a state of decay. The old builders used to bed the ends of girders and joists in loam, instead of mortar. In this place it may not be amiss to point out the dangerous consequences of building walls so that their principal support depends on timber. The usual method of putting bond-timber in walls is to lay it next the inside; this bond often decays, and of course leaves the wall resting only upon the external course or courses of bricks; and fractures, bulges, or absolute failures are the natural consequences. This evil is in some degree avoided by placing the bond in the middle of the wall, so that there is brick-work on each side, and by not putting continued bond for nailing the battens to.

18. Effect of Painting.—There is another cause that affects all wood most materially, which is the application of paint, tar, or pitch before the wood has been thoroughly dried. The nature of these bodies prevents all evaporation, and confines the internal moisture, which is the cause of sudden decay; both oak and fir posts may be brought into a premature state of decay by their having been painted prior to a due evaporation of their moisture; and painting affords no protection to timber against dry rot. On the other hand, the doors,

pews, and carved work of many old churches have never been painted, and yet they are often found to be perfectly sound, after having existed for centuries.

Painted floor-cloths are very injurious to wooden floors, and soon produce rottenness in the floors that are covered with them; as the painted cloth prevents the access of atmospheric air, and retains whatever dampness the boards may absorb, and therefore soon causes decay. Carpets are not so injurious, but still assist in retarding free evaporation.

19. Prevention of Decay is best obtained by a proper seasoning of timber, whatever the cause of decay may be, and the time required for a complete seasoning depends on the size of the pieces. But however well timber may be seasoned, if it be employed in a damp situation, decay is the certain consequence; therefore it is most desirable that the neighbourhood of buildings should be well drained, which would not only prevent the rot, but also increase materially the comfort of those who reside within them. The drains should be made water-tight wherever they come near to the walls; as walls, particularly brick walls, readily draw up moisture to a very considerable height. Earth should never be suffered to rest against walls, and the sunk stories of buildings should always be surrounded by an open area, so that the walls may not absorb moisture from the earth. To prevent moisture rising from the foundation, some substance that will not allow it to pass should be used at a course or two above the footings of the walls; sheets of lead or copper have been used for that purpose; to lay a few courses of slates or slaty stones, that do not absorb much moisture, would be useful; but a better method is to build a few courses in height with Portland cement, instead of common mortar, and upon the upper course

to lay a bed of about an inch in thickness of cement. As moisture does not penetrate this cement, it is an excellent material for keeping out wet; and it is also a great improvement to a brick building to stucco it on the outside with any cement which keeps out moisture, as brick absorbs quickly all the moisture which comes in contact with it, and retains it for a length of time.

20. Drying New Buildings.—The walls and principal timbers of a building should always be left for some time to dry after it is covered in. This drying is of the greatest benefit to the work, particularly the drying of the walls; and it also allows time for the timbers to get settled to their proper bearings, which prevents after-settlements and cracks in the finished plastering. It is sometimes said, that it is useful because it allows the timber more time to season; but when the carpenter considers that it is from the ends of the timber that much of its moisture evaporates, he will see the impropriety of leaving it to season after it is framed, and also the cause of framed timbers of unseasoned wood failing in the joints sooner than in any other place. No parts of timbers require the perfect extraction of the sap so much as those that are to be joined. Also, when the plastering is finished, a considerable time should be allowed for the work to get dry again, before the skirtings, and floors, and other joiner's works be fixed. Drying will be much accelerated by a free admission of air, particularly in favourable weather.

21. Prevention of Rising Damp.—When a building is thoroughly dried at first, openings for the admission of fresh air are not necessary where the precautions against any new accessions of moisture have been effectual. Indeed such openings only afford harbour

for vermin, as the current of air through them is very seldom capable of carrying off any considerable degree of moisture; for it is well known that air will not move in a horizontal direction without a more considerable change of density than can be obtained in such situations.

In floors next the ground we cannot easily prevent the access of damp, but this should be done as far as possible. All vegetable mould should be carefully removed, and if the situation admits of it, a considerable thickness of dry materials, such as brickbats, dry ashes, &c., but not lime, should be laid under the floor, and over these a coat of smiths' ashes, or of pyrites, where they can be procured. The timber for the joists should be well seasoned; and it is advisable to cut off all connection between wooden ground-floors and the rest of the wood-work of the building.

22. Impregnation of Timber.—It was long a general opinion that timber might be secured against the dry rot by impregnating it with some substance that would resist putrefaction: this opinion produced many schemes, and led finally to that recommended and patented by Mr. Kyan.

Common Salt (chloride of sodium) is found to protect the timber impregnated with it, when the proportion of salt is considerable. The large wooden props which support the roofs of the salt mines in Hungary, and are perpetually moistened with salt-water trickling down them, are said to have suffered no decay for many centuries; and the incrustations of salt upon the timbers of vessels employed in carrying salt-fish, preserve them a great number of years. There are, however, strong objections to using solutions of salt, unless it be where it is of no importance whether the wood be dry or wet; for the attraction of salt for moisture would keep the wood continually wet if moisture

should be present. SEA-WATER has been found effectual in clearing timber of fungus, by immersing it for several months. But unless a solution of salt, so strong as to be objectionable from its attraction of water, could be used, there appears to be no well-grounded hope of its being useful; as it is well known that common salt in small quantities assists the decomposition of vegetable matter.

23. IMPREGNATION WITH SULPHATE OF IRON appears to be more likely to answer the purpose of resisting putrefaction; wood boiled for three or four hours in a solution of sulphate of iron, and then kept some days in a warm place to dry, becomes so hard and compact that moisture cannot penetrate it.

QUICKLIME, it has been already stated, assists putrefaction when aided by moisture. But where a great quantity of quicklime is present, often in contact with the wood, so as to preserve it in a perfectly dry state, by the rapid absorption of water, this hardens the sap, and renders the wood very durable. Of this effect of lime we have proofs in the vessels formerly employed in the Sunderland lime trade, some of which were very sound when forty years old.

24. KYANIZING.—From the preceding articles it will be seen that the idea of preserving timber from rot by impregnating it with certain substances, is not of itself new; nor is even the employment of the substance itself recommended by Kyan, viz., corrosive sublimate (chloride of mercury), a novel application; for Sir H. Davy had before recommended a wash of a weak solution of this substance to check the progress of the rot in places where it had commenced, and which were under repair. Indeed corrosive sublimate had been long known as possessing great antiseptic virtues, and has been, as such, long employed by anatomists to prevent

the decay of the most delicate organic tissues and other parts liable to putrescence; and by the application of this metallic preparation they have been prevented from going to decay, and have been preserved for very long periods.

Kyan's process consists in applying this substance to timber for the prevention of rot; that is, cases of decay, arising either from the action of the seed of cryptogamous plants vegetating in the wood, or from the presence of the albuminous parts of the tree. In order to carry it into practice, large trunks of wood are prepared with cross beams, in order to wedge down the timbers placed therein for immersion; that is, the timber which is to undergo the process is first placed therein, under those beams, and wedged down so as to prevent it from rising when the fluid, impregnated with the corrosive sublimate, is introduced. In this state it remains for about a week. The fluid is then pumped off, the timber taken out and dried, and is thus considered to be secure against the action of the destructive vegetation and decomposition which have been found so injurious to every kind of timber structure, from the smallest closet to the largest man-of-war.

There could be no doubt, from experiments that were made, that the process which the different articles had undergone acted as a preservative from the rot, under the circumstances in which they had been placed; and the only doubt which seemed to hang over the inquiry was, whether the effect was permanent or temporary: if the effect were due to a simple impregnation, it might, under different circumstances, be removed, whereby the timber would be left in its original state, while a noxious atmosphere might be generated, which would be extremely injurious to health in many cases, and particularly in ships of war. It is therefore highly satisfactory

to state that Dr. Faraday decided from experiment that the effect is not that of a mere mechanical impregnation; but that a chemical combination takes place between the corrosive sublimate and the albuminous matter of the wood, forming thereby a new compound. This question being thus settled, we may next inquire to what depth the effect has taken place; and it appears that hitherto it has not been traced to more than about half an inch from the surface: and it remains, therefore, perhaps still doubtful whether it will be found fully effective in large timbers. These indeed will be protected from contagion from other decayed wood; but, for anything at present shown, the rot may commence in them internally; still, however, if even this should be the case, much has undoubtedly been effected.

Some question having arisen as to the effect of Kyan's process upon the strength of timber, experiments were made on two pieces of ash, parted only by the saw, two inches square and three feet long, and two pieces of Christiana deal of the same dimensions; one of each was prepared, the other two unprepared, and they were submitted to a trial of traverse strength and stiffness, at a clear bearing distance of 34 inches, when it appeared that the process diminished both the specific gravity and the strength of the timber, but that it increased its rigidity.

25. THE CURE OF ROT is very difficult, and would be nearly, if not quite, as expensive a process as to put in anew the timbers affected with it; but when new timber is put in, the old parts and the walls should have every particle of fungus removed from them, or killed by some wash for that purpose. External washes perhaps are not much further useful than so far as they hinder infection; but to produce that effect they are perhaps the best application, because they can be applied

with safety. A high degree of heat, that is, about 300°, would destroy all power of reproduction, but it cannot so well be applied: nevertheless, where pieces of wood are not materially injured by the rot, an oven might be contrived to expose them to a strong heat, which would destroy all vegetable life in the fungus, and they might then be washed with some of the solutions mentioned below, and used again with perfect safety.

A solution of CORROSIVE SUBLIMATE (*chloride of mercury*) would answer very effectually as a wash. A very weak solution does not produce the desired effect; there should be an ounce of corrosive sublimate to a gallon of water, and it should be laid on hot. No other metallic solution should be mixed with it.

A solution of *sulphate of copper*, in the proportion of about half a pound of sulphate to one gallon of water, used hot, makes an excellent wash, and is cheaper than the preceding one.

A strong solution of *sulphate of iron* is sometimes used, but is not so effectual as that of copper; and sometimes a mixture of the two solutions has been used.

Coal tar is said to have been found beneficial; but its strong smell is a great objection to its use; where the smell is not of importance, it would assist in securing new timber which had been previously well dried.

Charring new wood can only be expected to prevent infection; decay may begin at the centre, and proceed without ever appearing at the surface of the beam; and therefore if timber be not well seasoned, no permanent good can be obtained from charring.

26. PROTECTION OF THE SURFACE OF TIMBER.—When timber is exposed to the alternate action of dryness and moisture, the best means of securing it from decay is the protection of the surface by a coat of some substance that moisture will not penetrate.

The Dutch, for the preservation of their gates, drawbridges, sluices, and other large works of timber, which are exposed to the sun and perpetual injuries of the weather, coat them with a mixture of *pitch and tar*, upon which they strew small pieces of cockle and other shells, beaten almost to powder, and mingled with sea-sand, or the scales of iron beaten small and sifted, which protects them in a most excellent manner. *Upon common painting, sanding is an excellent practice, where it is exposed to the weather, being much more durable than common painting.*

It has been proposed to apply a paint made of sub-sulphate of iron (the refuse of the copperas pans), ground up with any cheap oil, and rendered thin with coal-tar oil, in which a little pitch had been dissolved. In the neighbourhoods of Newcastle and Glasgow the refuse of the copperas pans may be easily procured.

Another method of protecting timber appears to be so well calculated for the purpose, that in cases where it can be applied a better cannot be employed. After the work is tried up, or even put together, lay it on the ground with stones or bricks under it to about a foot high, and burn wood (which is the best firing for that purpose) under it till you thoroughly heat, and even scorch it all over; then, whilst the wood is hot, rub it over plentifully with linseed oil and tar, in equal parts, well boiled together, and let it be kept boiling whilst you are using it; and this will immediately strike and sink (if the wood be tolerably seasoned) one inch or more into the wood, close all the pores, and make it become exceedingly hard and durable, either under or over water. No composition should, however, be applied till the timber has been well seasoned: for to inclose the natural juices of the wood is to render its rapid decay certain.

27. The Ravages of Worms and Insects are among the principal causes of the destruction of timber; some woods are more subject to be destroyed by them than others, such as alder, beech, birch, and, in general, all soft woods, of which the juices are of a saccharine nature. Against the common worm, *oil of spike* is said to be an excellent remedy, and the *oil of juniper*, or of *turpentine*, will prevent them in some degree. A free use of *linseed oil* is a good preventive, and so is a covering of *copal varnish*; but these can be applied to small articles only. Another application is *sulphur* which has been immersed in nitric acid, and distilled to dryness, which, being exposed to the air, dissolves into an oil: the parts to be secured from the worm are to be anointed with this oil, which does not give an unpleasant odour to the wood. *Lime* is an excellent preservative against the worm, and sap-wood should always be impregnated with it when used in a dry situation. As worms do not attack bitter woods, soaking wood in an infusion of quassia has been tried, and is said to have the desired effect.

28. Teredo, Tholas, and Lepisma.—The bottoms of ships, and timbers exposed to the action of the sea, are often destroyed by the pipe-worm, or *Teredo navalis* of naturalists. This creature is very small when first produced from the egg, but soon acquires a considerable size, being often three or four inches in length, and sometimes increases to a foot or more in length. Its head is provided with a hard calcareous substance, which performs the office of an auger, and enables it to penetrate the hardest wood. When a piece of wood, constantly under water, is occupied by these worms, there is no sign of damage to be seen on the surface, nor are the worms visible till the outer part of the wood is broken or cut away; yet they lie so near the

surface as to have an easy communication with the water by a multitude of minute perforations. They were originally brought from India to Europe. Wood is eaten by them till it becomes like a honeycomb, yet there is an evident care in these creatures never to injure one another's habitations, for the divisions between the worm-holes are entire, though often extremely thin. Fir and alder are the two kinds of wood they seem to destroy with the greatest ease, and in these they grow to the greatest size. In oak they make slower progress, appear smaller and not so well nourished. They never touch bitter woods, and in solid or hard woods they make slow progress. Charring the surface of wood is not found to be of any use.

A mixture of *lime, sulphur, and colocynth, with pitch*, is found to be a protection to boards and the like. And rubbing the wood with *poisonous ointments* is a means of destroying them. A mixture of *tar, pitch*, and the *animal hair* separated in tanning was formerly applied, with a sheathing of wood to keep it on, and lately the hair has been felted to apply under copper. A covering of thin *copper*, with felting tarred between it and the wood, is the best protection for the bottoms of ships from all marine animals.

A species of tholas (*Tholas striata*) is another animal which is very destructive, not to timber only, but to stones, clay, &c., in water. They make their attack in a similar manner to the pipe-worm, by burrowing when young, the entrances of the holes only about one-fourth of an inch in diameter; and the animal, increasing in growth as it advances, forms a larger hole, till it arrives at maturity, when it ceases to bore. It derives its sustenance from the water, and never bores so far that it cannot reach the water with its proboscis.

The lepisma is also a destructive little animal, which

begins to prey on wood in the East Indies as soon as it is immersed in sea-water. The unprotected bottom of a boat has been known to be eaten through by it in three or four weeks: sheathing with *copper* or covering with *felt* are the most certain means of protection against all these marine animals. *Coal tar* is also a good protection against their depredations; the pores of the wood should be saturated as far as possible with it; and perhaps *corrosive sublimate* might be used with advantage, by saturating the wood with a solution of it, and letting it dry before the tar be laid on. *Whale oil* is stated to be an effectual remedy, and has been successfully employed.

29. THE WORM.—There is another kind of worm very destructive to timber, which Mr. Smeaton observed in Bridlington piers. The wood of these piers, he says, is destroyed by a certain species of worm, differing from the common worm, whereby ships are destroyed. This worm appears as a small, white, soft substance, much like a maggot; so small as not to be seen distinctly without a magnifying glass, and even then a distinction of its parts is not easily made out. It does not attempt to make its way through the wood longitudinally, or along the grain, as is the case with the common ship worm; but directly, or rather a little obliquely, inward. They do not appear to make their way by means of any hard tools or instruments, but rather by some species of dissolvent liquor, furnished by the juices of the animal itself. The rate of progression is such that a three-inch oak plank will be destroyed in eight years by their action from the outside only. Fir is more subject to be destroyed by this worm than oak. To prevent the destructive effects of these worms, Mr. Smeaton recommended that the timbers of the piers should be squared, and made to fit as close together

as possible; to fill all the openings left with tar and oakum, and level the face, and cover it with sheathing, as ships are covered. These worms do not live except where they have the action of the water almost every tide; nor do they live in the parts covered with sand. The wooden piles of embankments and sea-locks suffer much from these worms; and in the sea-dykes of Holland they cause very expensive annual repairs. The remedies that resist the ship worm would no doubt be effectual against these.

30. THE TERMITE, or WHITE ANT, is the greatest calamity of both Indies, because of the havoc they make in all buildings of wood, in utensils, and in furniture; nothing but metal or stone can escape their destructive jaws. They frequently construct nests within the roofs and other parts of houses, which they destroy if not speedily extirpated. The larger species enter under the foundations of houses, making their way through the floors, and up the posts of buildings, destroying all before them. And so little is seen of their operations, that a well-painted building is sometimes found to be a mere shell. *Corrosive sublimate* is highly poisonous to these ants; therefore, to impregnate the timber with a solution of it would prevent their ravages. *Arsenic* is also very destructive to them, and they do not destroy wood impregnated with *oil*, particularly essential oils; *cajeput oil* was found effectual in destroying the red ants of Batavia.

31. THE DURABILITY OF TIMBERS which the carpenter employs is a subject to which he cannot be insensible; nor can he be uninterested in any inquiry into the probable extent of their duration. Of the durability of timber in a *wet* state, the piles of the bridge built by the Emperor Trajan across the Danube are an example. One of these piles was taken up, and

found to be petrified to the depth of three-fourths of an inch; but the rest of the wood was little different from its ordinary state, though it had been driven more than sixteen centuries. The piles under the piers of old London Bridge had been driven about six hundred years, and were found to the last sufficiently sound to support the superstructure. They were chiefly of elm.

32. Buried Timber.—We have also some remarkable instances of the durability of timber when buried in the ground. Several ancient canoes have been found in cutting drains through the fens in Lincolnshire, which must have lain there for many ages. Also, in digging away the foundation of old Savoy Palace, London, which was built six hundred and fifty years ago, the whole of the piles, consisting of oak, elm, beech, and chestnut, were found in a state of perfect soundness; as also was the planking which covered the pile-heads. Some of the beech, however, after being exposed to the air a few weeks, though under cover, had a coating of fungus spread over its surface. A continued range or curb of timber was discovered in pulling down a part of the Keep of Tunbridge Castle, in Kent, which was built about seven hundred years ago. This curb had been built into the middle of the thickness of the wall, and was no doubt intended to prevent the settlements likely to happen in such heavy piles of building; and therefore is an interesting fact in the history of constructive architecture, as well as an instance of the durability of timber. In digging for the foundations of the present house at Ditton Park, near Windsor, the timbers of a drawbridge were discovered about ten feet below the surface of the ground; these timbers were sound, but had become black; the timber had been there about four hundred years.

33. THE DURABILITY OF THE FRAMED TIMBERS OF BUILDINGS is very considerable. The fir trusses of the old part of the roof of the Basilica of St. Paul, at Rome, were framed in 816, and were sound and good in 1814. The timber-work of the external domes of the Church of St. Mark, at Venice, is more than eight hundred years old, and is still said to be in a good state; and the gates of cypress to the Church of St. Peter, at Rome, were whole and sound after being up five hundred and fifty years. The inner roof of the chapel of St. Nicholas, King's Lynn, Norfolk, is of oak, and was constructed about four hundred and fifty years ago; the large dormitory of the Jacobins' Convent at Paris, executed in fir, lasted four hundred years. The timber roof of Crosby Hall, in London, was executed about three hundred and sixty years ago; and the roof of Westminster Hall, which is of oak, is now above four hundred and fifty years old.

34. THE RELATIVE DURABILITY OF DIFFERENT WOODS.—The most odoriferous kinds of woods are generally esteemed the most durable; also woods of a close and compact texture are generally more durable than those that are open and porous; but there are exceptions, as the wood of the evergreen oak is more compact than that of the common oak, but not nearly so durable. In general, the quantity of charcoal afforded by woods offers a tolerably accurate indication of their durability: those most abundant in charcoal and earthy matter are most permanent; and those which contain the largest proportion of gaseous elements are the most destructible. The chestnut and the oak are pre-eminent as to durability, and the chestnut affords rather more carbonaceous matter than the oak. But this is not always the case, as we know from experience that red or yellow fir is as durable as oak in most situations,

though it produces less charcoal by the ordinary process. An experiment to determine the comparative durability of different woods is related in Young's "Annals of Agriculture," which will be more satisfactory than any speculative opinion; and it is much to be regretted that such experiments have not been oftener made. Inch-and-half planks of trees from thirty to forty-five years' growth, after ten years' standing in the weather, were examined and found to be in the following state:—

Cedar, perfectly sound.	Chestnut, perfectly sound.
Larch, the heart sound, but sap quite decayed.	Abele, sound.
Spruce fir, sound.	Beech, sound.
Silver fir, in decay.	Walnut, in decay.
Scotch fir, much decayed.	Sycamore, much decayed.
Pinaster, quite rotten.	Birch, quite rotten.

This shows at once the kinds that are best adapted to resist the weather; but even in the same kind of wood there is much difference in the durability; and it is observed that the timber of those trees which grow in moist and shady places is not so good as that which comes from a more exposed situation, nor is it so close, substantial, and durable. Also split timber is more durable than sawn timber, for in splitting, the fissure follows the grain, and leaves it whole, whereas the saw divides the fibres, and moisture finds more ready access to the internal parts of the wood. Split timber is also stronger than sawn timber, because the fibres being continuous, they resist by means of their longitudinal strength; but when divided by the saw, the resistance often depends upon the lateral cohesion of the fibres, which is in some woods only one-twentieth of the direct cohesion of the same fibres. For the same reason whole trees are stronger than specimens, unless the specimens be selected of a straight grain; but the difference in large scantlings is so small as not to be deserving of notice in practice.

Section IV.—The Structure and Classification of Woods

35. Characters of Woods.—To the experienced eye of a workman the general appearance of each variety of wood has become so familiar, and its most obvious characters are so strongly impressed on his memory, that he readily knows them one from another; but, nevertheless, the notice of some characters that are peculiar to certain kinds of woods may be of use even to the initiated. In a section of a tree it clearly appears that the wood is composed of separate layers, or rings, regularly disposed round the pith, which is in general nearly in the centre of the tree; but the thickness of these layers is seldom, if ever, perfectly regular. When examined by a magnifier, the wood appears to consist of fine divisions, like rays, spreading from the pith to the bark, with pores between them, often empty, but sometimes filled with some kind of vegetable matter. In the resinous woods most of the pores are filled. Besides the fine divisions, which are often scarcely to be distinguished by the naked eye, there are, in some woods, other divisions that are larger, passing from the pith to the bark; these are generally of a light silvery colour, and are called the silver grain, or larger transverse septa. When a piece of wood is cut so as to pass obliquely through the larger septa or silver grain, it produces that fine flowered appearance so well known in the oak. The fine divisions, or lesser transverse septa, are common to all woods except the palm, though in some way they are not very distinct. But there are only some kinds that have the larger septa, or silver grain; therefore this forms a natural character for distinguishing the kinds of wood. And they may be divided into two classes—one that has, and the other that has not, the larger septa or silver grain.

Again, in some woods each annual layer or ring seems to be nearly uniform in its texture, and the line of separation between the layers is not very distinct. Mahogany is an example of this structure. But in other woods one part of the layer is nearly compact, and the rest of it presents the appearance of a circle of empty pores; of which we have an example in the ash There is a third kind, in which nearly all the pores appear to be filled with resinous or gummy matter; and one part of the layer consists of a compact, hard, and dark-coloured substance, the other part is lighter coloured and softer. All the resinous woods are of this kind.

According to these distinctions, the arrangement of the following table is made :—

WOODS.	CLASS I.—With larger transverse septa, or medullary rays.	*Division* 1.—Very distinct annual rings, one side porous, the other compact.	Oak.
		Division 2. — Annual rings not very distinct, and their texture nearly uniform.	Beech. Alder. Plane. Sycamore.
	CLASS II.—No larger transverse septa.	*Division* 1. — Annual rings very distinct, one side porous, the other compact.	Chestnut. Ash. Elm. False acacia.
		Division 2. — Annual rings not very distinct, and their texture nearly uniform	Mahogany. Walnut. Teak. Poona. African teak. Poplar.
		Division 3. — Annual rings very distinct, pores filled with resinous matter; one part of the ring hard and heavy, the other soft and lighter coloured.	Cedar of Lebanon Larch. Yellow fir. White fir. American pine. Cedar. Cowrie.

36. THE PROPERTIES OF WOOD which seem to require explanation are the cohesive force, the modulus of elasticity, permanent alteration, the stiffness, the hardness, and the toughness. The *cohesive force* of a bar or beam is equal to the power or weight that would pull it asunder in the direction of its length. The weight that would pull asunder a bar of an inch square of different kinds of wood has been ascertained by experiments. Of these experiments we have taken the highest and lowest result for each kind of wood. The *modulus of elasticity* is the measure of the elastic force of any substance. As it is the measure of the elastic force, its use must be evident when it is considered that it is only the elastic force of timber that is employed in resisting the usual strains in carpentry; and the constant numbers employed in the rules for the stiffness of timber have for one of their elements the modulus of elasticity. By means of the modulus of elasticity the comparative *stiffness* of bodies can be ascertained. For instance, its weight for cast-iron is 18,240,000 pounds, and its weight for oak is 1,714,500 pounds. Hence it appears that the modulus for cast-iron is 10·6 times that of oak, and therefore a piece of cast-iron is 10·6 times as stiff as a piece of oak of the same dimensions and bearing.

Permanent alteration of structure takes place when a certain degree of strain continues for above a certain time; and as this alteration is a partial fracture, or at least failure of the material, it is of the greatest importance that the strain should never be more than that producing such alteration, and in timber this appears to be about one-fifth of the cohesive force.

A *hard* body is that which yields least to any stroke or impressive force; and it may be shown, by the principles of mechanics, that in uniform bodies the degree

of yielding is always proportional to the weight of the modulus of elasticity; therefore a table containing the weights of the modulus of elasticity of such bodies shows also their relative hardness and stiffness. The relative *hardness* is determined with considerable accuracy by means of the modulus of elasticity. As the hardness follows the same laws as the stiffness, cast-iron is 10·6 times as hard as oak; but when the substance is not uniform, the hardness thus found is that of the hardest part. Thus, in fir, it is the darker part of the annual ring that is the hardest, and which determines the extent to which a beam will bend without fracture. Dry wood is harder than green; consequently it is more difficult to work. The labour of sawing dry oak is to that of sawing green as 4 is to 3, nearly.

In respect to the *toughness* of woods, that wood is the toughest which combines the greatest degree of strength and flexibility; hence that wood which bears the greatest load, and bends the most at the time of fracture, is the toughest.

The opposite to hardness is softness, the opposite to toughness is brittleness, and the opposite to stiffness is flexibility; therefore, when the hardness, toughness, or stiffness of a wood is expressed by a low number, it may be considered to have the opposite quality.

Oak in the following articles has been made the standard of comparison; its strength, toughness, and stiffness each having been assumed to be 100; and in so doing, the mean strength of oak is taken at 11,880 pounds per square inch, and its modulus of elasticity at 1,714,500 pounds for a square inch.

The above-mentioned properties determine the fitness of woods for the different purposes of carpentry. In some cases stiff woods are required, as in the joists

and rafters of a building; in other cases tough wood should be employed, as for the shafts of carriages; and in other cases strength is necessary, as in ties and other timbers strained in the direction of their length.

Tough woods, which are also hard, are the most difficult to work, especially if cross-grained; on the contrary, brittle woods work easily; and hard woods preserve the best surface.

In general, where straightness is desirable, stiff woods should be preferred; where sudden shocks are to be sustained, tough woods are the best; where little strength is required, but much labour is to be put upon it, a soft brittle wood should be preferred; and where a fine surface is to be preserved, a hard wood should be chosen; so that it is not in carpentry alone that these researches will be useful, for they are equally applicable to any art where timber is employed; and particularly in that most important application of carpentry, Naval Architecture.

37. DESCRIPTION OF WOODS. CLASS I.—The woods of this class are compact, hard, and heavy; never very deep-coloured, the oak being the darkest-coloured of the class. They are nearly free from smell, and never resinous.

This class is formed into two divisions: one containing those woods in which the annual rings are distinctly porous on one side, and compact, or nearly compact, on the other; the other division contains those in which the annual rings are sensibly uniform, and only to be distinguished by a difference of colour.

38. DIVISION I.—THE OAK (*Quercus*) is a tree of which there are several species, that produce valuable timber.

Common British oak (*Quercus robur*) is found throughout the temperate parts of Europe, and is that

which is most commonly met with in the woods and hedges of the south of England; it grows to a very large size. The wood of this species has often a reddish tinge; the larger septa are always very numerous, producing large flowers; the grain is tolerably straight and fine, and it is generally free from knots; sometimes closely resembling foreign wainscot. It splits freely, and makes good laths for plasterers and slaters; and it is decidedly the best kind of oak for joists, rafters, and for any other purposes where stiff and straight-grained wood is desirable.

The sessile-fruited oak (*Quercus sessiliflora*) is a native of the woods and hedges of the temperate parts of Europe, and it appears to be the common oak of the neighbourhood of Durham, and perhaps generally of the north of England. The wood is of a darker colour than that of the robur, and the larger septa are not so abundant; sometimes there are very few septa. The smoothness and gloss of the grain makes it resemble that of chestnut. It is heavier, harder, and more elastic than the wood of the robur, and is very subject to warp and split in seasoning. It is very tough and difficult to split, therefore not fit for laths. This is most probably the reason that oak laths are so seldom used in the north of England. In respect to the comparative durability of the woods of the two species, it is a question that requires to be investigated. It appears, as far as can be determined from the structure of the wood, that the fine oak found in old Gothic roofs is of the sessile-fruited kind. At the same time it must be owned that our means of judging are not so satisfactory as to enable us to decide on this point with certainty; but we know that the old oak is very durable.

The strength, elasticity, toughness, and hardness of

the sessile-fruited oak render it superior for ship-building; but it is both heavier and more difficult to work than the robur; how far they may differ in durability remains to be determined.

The following table shows the results of trials on two pieces, each piece an inch square, and sustained by supports 24 inches apart, the weight being applied in the middle of the length:—

Species of oak.	Specific gravity.	Weight of a cubic foot in lbs.	Comparative stiffness or wt. that bent the piece seven-twentieths of an inch.	Comparative strength or weight that broke the piece.
			Pounds.	Pounds.
Quercus sessiliflora .	·807	50·47	167	322
Quercus robur .	·879	54·97	149	350

Both these specimens broke short without splitting; therefore these experiments offer a very fair view of the properties of the two species. The sessiliflora bent considerably more at the time of fracture than the robur, but it could not be measured with that correctness which is necessary to render such data useful.

The following table contains the values of the cohesive force, and modulus of elasticity, calculated from the above experiments:—

Species of oak.	Cohesive force of a sq. in. in lbs.	Wt. of modulus of elasticity in lbs. for a sq. in.	Comparative toughness.
Quercus robur .	11,592	1,648,958	81
Quercus sessiliflora .	12,600	1,471,256	108

These pieces were hastily, and therefore imperfectly,

seasoned; but as they were treated exactly alike, this would not affect the comparison.

There is another species, called the Durmast oak, which is a native of France and the south of England; its wood is not so strong nor of so firm a texture as the English oak, and it retains its foliage much later. The Austrian oak is a taller tree than the English oak; but the wood is whiter, softer, and less valuable. Of the American species the chestnut-leaved oak is a tall tree, remarkable for the beauty of its form: the wood is cross-grained, but is very serviceable, and is much used for wheel carriages.

The mountain red oak (*Quercus rubra*) is a native of Canada and the country west of the Alleghany mountains. It is called the red oak, from the leaves changing to a red or purple colour before they fall off. It is a large and fine tree, of 90 or 100 feet in height, and of rapid growth; the wood is useful for many purposes, but it is light, spongy, and not very durable. The white oak (*Quercus alba*), so called from the whiteness of its bark, is a native of the woods from New England to Carolina, and acquires an immense size in some of the middle States. Its wood is tough and pliable, and it is preferred to all others in America both for house and ship carpentry, being much more durable than most other species. It is less durable than British oak, but it is of quicker growth. The blunt-lobed iron oak (*Quercus obtusiloba*) is another of the American species that produces very valuable ship timber. The wood is hard, and not liable to decay, and is preferred for fencing. It is found in most of the upland forests from Canada to Florida, and is a tree of 60 or 70 feet in height. But the live oak (*Quercus virens*) is esteemed the best of the American kinds for ship timber. It grows to the height of 40 or 50 feet,

with wide-spreading branches, and the wood is very durable.

Oak of a good quality is more durable than any other wood that attains a like size. The more compact it is, and the smaller the pores are, the longer it will last; but the open, porous, and foxy-coloured oak, which grows in some parts of Lincolnshire, and in some other places, is not nearly so durable. It is useful for most of the purposes of the carpenter, and particularly in situations where it is exposed to the weather. It makes the best wall-plates, ties, templets, king posts, and indeed it is best suited for every purpose where its warping in drying and its flexibility do not render it objectionable; but it is very subject to twist and occasion cracks in the work it is employed in.

The colour of the oak is a fine brown, and is familiar to every one. It is of different shades; that inclined to red is the most inferior kind of wood. The larger transverse septa are in general very distinct, producing beautiful flowers when cut obliquely. Where the septa are small and not very distinct the wood is much the strongest. The texture is alternately compact and porous; the compact part of the annual ring being of the darkest colour, and in irregular dots, surrounded by open pores, producing beautiful dark veins in some kinds, particularly in pollard oaks.

The young wood of English oak is very tough, often cross-grained, and difficult to work, and does not combine well with glue. Foreign wood, and that of old trees, is more brittle and workable. Oak warps and twists much in drying, and shrinks about one thirty-second part of its width in seasoning.

The weight of a cubic foot of different kinds, when seasoned, is as follows :—

English oak, from	40 to 58 lbs.
Riga oak	43 to 54 ,,
Red American oak	37 to 47 ,,
White American oak	50 to 56 ,,
Adriatic oak	58 to 68 ,,

Representing the strength, stiffness, and toughness of the common English oak (*Quercus robur*) each by 100, it may be compared with the other kinds as under :—

	Com. Eng.	Riga.	American.	Dantzic.
Strength . . .	100	108	86	107
Stiffness . . .	100	93	114	117
Toughness . .	100	125	64	99

The specimens of Riga and Dantzic oak were of the best quality.

39. Division II.—In this division there are several species; but only four are here described—namely, beech, alder, plane, and sycamore. The woods of this division are very uniform in their texture, and very durable in water: they are useful for piles and planking in wet situations, but not applicable to other kinds of carpenters' work. Woods of this division do not warp so much as those of the first division.

40. The Beech Tree (*Fagus sylvatica*) has but one species, the common beech, the difference in the wood proceeding from the difference of soil and situation; but owing to this difference the wood is distinguished by the names brown or black, and white beech. It is common in Europe, especially on a rich chalky soil. The best beeches grow on a good soil, more dry than moist; and the wood is whiter than that of those

grown in damp valleys, which loses its strength in drying, and becomes brittle. The mean size of the trunk of the beech tree is about 44 feet in length and 22 inches in diameter.

Beech is durable when constantly immersed in water, but damp soon destroys it. In a dry state it is more durable, but is soon injured by worms, whether it be in a damp or in a dry state. Water-seasoned beech is much less subject to worms than that seasoned in the common way; and to preserve it from worms, it ought to be cut about a fortnight after midsummer, and planked immediately; then the planks should be put in water about ten days, and afterwards dried.

Beech is not useful in building, because it rots so soon in damp places, but it is useful for piles in situations where it will be constantly wet; and it is very useful for various tools, for which its uniform texture and hardness render it superior to any other wood. It is also much used for furniture.

The colour of beech is a whitish brown, of different shades; the darker kind is called brown, and sometimes black beech; the lighter kind is called white beech. The texture is very uniform; the large septa are finer, and do not extend so far in the length of the wood as in oak; therefore the flowers are smaller. The annual rings are rendered visible by being a little darker on one side than the other. It is very uniformly porous, and might be easily made to imbibe some ingredient that would prevent the worms destroying it. It has no sensible taste or smell; it is not very difficult to work, and may be brought to a very smooth surface. The white kind is the hardest, but the black is tougher, and more durable than the white.

The mean cohesive force of a square inch of beech is 12,000 pounds; the weight of its modulus of elasticity

is about 1,316,000 pounds; the weight of a cubic foot dry varies from 43 to 53 pounds.

Representing the strength of oak by	100, that of beech will be	.	103
„ „ stiffness of oak by	100, „ „	.	77
„ „ toughness of oak by	100, „ „	.	138

Hence it appears that oak is superior in stiffness but neither so strong nor so tough.

41. THE ALDER TREE (*Betula alnus*) is a native of Europe and Asia, that grows in wet grounds and by the banks of rivers. The tree seldom exceeds 40 feet in height. The wood is extremely durable in water or wet ground, but it soon rots when exposed to the weather, or to damp; and in a dry state it is much subject to worms. On account of the durability of alder in water, it is esteemed valuable for piles, planking, sluices, pumps, and, in general, for any purpose where it is constantly wet. And for such purposes it has been much cultivated in Holland and Flanders. It is also used for turners' wares and other light purposes.

The colour of alder is a reddish yellow, of different shades, and nearly uniform. The texture is very uniform, with large septa of the same colour as the wood, therefore not very distinct, nor producing sensible flowers. It is soft, and works very easily; would cut well in carving, and make very good models for casting from. The cohesive force of a square inch of alder varies from 5,000 to 13,900 pounds: its modulus of elasticity is 1,086,750 pounds for a square inch; and a cubic foot weighs from 34 to 50 pounds in a dry state.

Representing the strength of oak by	100, that of alder will be	.	80
„ „ stiffness of oak by	100, „ „	.	63
„ „ toughness of oak by	100, „ „	.	101

42. THE PLANE TREE has several species; the most common are the oriental plane and the occidental

plane The oriental plane (*Platanus orientalis*) is a native of the Levant and other eastern countries, and is considered one of the finest of trees. It attains about 60 feet in height, and has been known to exceed eight feet in diameter. Its wood is much like beech, but more figured, and is used for furniture and things of a like nature. The Persians employ it for their furniture, doors, and windows. The occidental plane (*Platanus occidentalis*) is a native of North America, and is perhaps one of the largest of the American trees; on the fertile banks of the Ohio and Mississippi some of the trees exceed 12 feet in diameter. The wood of the occidental plane is harder than that of the oriental kind, but the occidental is the most common in Britain, and to it only the rest of this article applies.

The colour of the wood of the plane tree is nearly the same as that of beech, and it also closely resembles it in structure; it differs in the larger septa, as in the plane the septa are more numerous, producing very beautiful flowers when properly cut. It works easily, and stands very well.

The cohesive force of a square inch is about 11,000 pounds; its modulus of elasticity is 1,343,000 pounds per square inch; and it weighs from 40 to 46 pounds per cubic foot when dry.

Representing	the	strength of oak by 100,	that of plane tree will be			92
"	"	stiffness of oak by 100,	"	"	.	78
"	"	toughness of oak by 100,	"	"	.	108

The wood of the occidental plane is very durable in water, and on that account the Americans use it for wooden quays in preference to any other kind.

43. THE SYCAMORE, or GREAT MAPLE (*Acer pseudo-platanus*), generally called the plane tree in the north

of England, is a native of the mountains of Germany, and is very common in Britain. It is a large tree, of quick growth, and thrives well near the sea; the mean size of its trunk is about 32 feet in length, and 29 inches in diameter. The wood is durable in a dry state, when it can be protected from worms; but it is equally as subject to be destroyed by them as beech. It is used chiefly for furniture, and the white wood of this tree is valuable for many ornamental articles.

The colour of sycamore is generally of a brownish white; sometimes of a yellowish white, or nearly white in young wood, with a silky lustre. Its texture is nearly uniform, and the annual rings not very distinct. Its larger septa are small and close, and perhaps it might be more correctly described as having distinct smaller septa, and no larger septa. It is in general easy to work, being less hard than beech. The cohesive force of a square inch varies from 5,000 to 10,000 pounds; its modulus of elasticity is 1,036,000 pounds for a square inch. A cubic foot of sycamore weighs from 34 to 42 pounds when dry.

Representing the strength of oak by	100, that of sycamore is .	81
" " stiffness of oak by	100, " " . .	59
" " toughness of oak by	100, " " . .	111

44. Class II. contains all woods that have no larger transverse septa. To this class many woods belong, and of various colours and qualities. There are three divisions: the first and second formed on the same distinctions as the first and second in the first class (37); the third division includes all the woods of which the pores are filled with resinous matter.

Division I.—In the first division of the second class the annual ring is nearly compact towards one side, and porous towards the other; and from this inequality the wood is very subject to warp in drying.

Four varieties are here described—the chestnut, ash, elm, and false acacia.

45. THE CHESTNUT (*Fagus castanea*) is commonly called the *sweet* or *Spanish* chestnut. This tree is a native of the warmer mountainous parts of Europe, and was once very common in this country; indeed it appears to have been one of the chief timbers used in earlier times. It is one of the largest and most long-lived of European trees, sometimes enduring more than a thousand years. The mean size of its trunk is about 44 feet in length and 37 inches in diameter; and it is of a rapid growth. The chestnut contains only a very small proportion of sap-wood, and therefore the wood of young trees is found to be superior even to oak in durability. The roof of King's College, Cambridge, may be cited as an example of its durability in a dry state; also the roof of the Church of Nôtre Dame at Paris.

Chestnut is useful for the same purposes as oak, when the timber is not from old trees; but the wood of old trees is unfit for any situation where an uncertain load is to be borne, as it is brittle, and often makes a fair show outwardly when it is decayed and rotten within; it is also liable to rot when built in a wall, and therefore the ends of joists of this wood should have a free space left round them.

The wood of the chestnut is nearly of the same colour as that of the oak. In old wood the sap-wood of chestnut is whiter and the heart-wood browner; but it is so much like oak that in old buildings they have been sometimes mistaken the one for the other. Chestnut has no large transverse septa, which is its chief distinction, and renders it easy to know it from oak, whether the wood be old or not. The wood is hard and compact; young wood is tough and flexible; old

wood is brittle, and often shaky. It does not shrink and swell so much as other woods, and is easier to work than British oak.

The cohesive force of a square inch of chestnut varies from 9,570 to 12,000 pounds when dry. The weight of a cubic foot dry is from 43 to 54·8 pounds. The properties as determined from a piece of young wood in a green state are as under. The cohesive force of a square inch of green chestnut is 8,100 pounds; the weight of the modulus of elasticity per square inch of ditto is 924,750 pounds; the weight of a cubic foot of ditto, 54·68 pounds.

Representing the—

strength of dry oak by	100, that of green chestnut is .	68
stiffness of dry oak by	100, " " .	54
toughness of dry oak by	100, " " .	85

It bends more than oak at the time of fracture, and therefore is tougher. Its toughness seems to permit it to yield insensibly till every particle exerts its utmost force, and then it gives way at once, more in the manner of metals than in that of woods.

46. THE COMMON ASH (*Fraxinus excelsior*) is a native of Europe and the north of Asia, and is the most valuable of the genus. There are other species both in America and other places; but we know nothing worthy of notice respecting their wood. The ash is a very rapid growing tree, and, like the chestnut, the young wood is much more valuable than that of old trees. No timber differs more from a difference of soil and situation than the ash. The mean size of the trunk is 38 feet in length and 23 inches in diameter; but sometimes this tree attains an immense size. Ash soon rots when exposed to either damp or alternate dryness and moisture; but is tolerably durable in a dry situation.

Ash is superior to any other British timber for its toughness and elasticity; and in consequencee of these properties, it is useful wherever sudden shocks are to be sustained; as in various parts of machines, wheel carriages, implements of husbandry, ship blocks, tools, and the like. It is too flexible for the timbers of buildings, and not sufficiently durable.

The colour of the wood of old trees is oak-brown, with a more veined appearance, the veins darker than in oak; sometimes the wood is very beautifully figured. The wood of young trees is brownish white, with a shade of green. Its texture is alternately compact and porous, the compact side of the annual ring being the darker coloured, which renders the annual rings very distinct. It has no larger septa, and consequently it has no flowers. It has neither taste nor smell, and is difficult to work, except the wood of old trees, which is of a more brittle nature.

The cohesive force of a square inch varies from 6,300 to 17,000 pounds; and the weight of its modulus of elasticity is about 1,525,500 pounds per square inch. The weight of a cubic foot dry varies from 34 to 52 pounds; when the weight of a cubic foot is lower than 45 pounds, the wood is that of an old tree, and will be found deficient both in strength and toughness.

Representing the strength of oak by	100, that of ash is	. .	119
" " stiffness of oak by	100, " "	. .	89
" " toughness of oak by	100, " "	. .	160

It exceeds oak both in strength and toughness, and in young wood the difference is still more considerable.

47. The Elm Tree (*Ulmus*) has five species now common in Britain, viz., the common rough-leaved elm, the cork-barked elm, the broad-leaved elm or wych hazel, the smooth-leaved or wych elm, and the Dutch

elm. The common rough-leaved elm (*Ulmus campestris*) is common in scattered woods and hedges in the southern parts of England; it is harder and more durable wood than the other species; it resists moisture well, and is therefore preferred for coffins. The cork-barked elm (*Ulmus suberosa*) is very common in Sussex; the wood is of an inferior kind, very much resembling Dutch elm. The broad-leaved elm or wych hazel (*Ulmus montana*) appears to be the most common species throughout Europe; it is frequent in the woods and hedges of England, particularly in the northern counties. The smooth-leaved or wych elm (*Ulmus glabra*) is common in England and Scotland. It grows to a large size, and is much esteemed; it is readily distinguished by its smooth, dark, lead-coloured bark, and by its leaves being nearly smooth on the upper surface. The wood is tough and flexible, and is stated to be preferred for naves of wheels. The Dutch elm (*Ulmus major*) is a native of Holland, and its wood is very inferior to the other species. The wych elm is the largest tree, and the Dutch elm the smallest. The mean size of the trunk of the elm tree is 44 feet in length and 32 inches in diameter. The trunk of the common rough-leaved elm is often rugged and crooked, and the tree is of slow growth.

Elm has always been much esteemed for its durability in situations where it is constantly wet; and it is also said to be very durable in a perfectly dry state, but not when exposed to the weather. The piles upon which old London Bridge stood were chiefly of elm, and remained six centuries without material decay; and several other instances of its durability in water have been noticed.

Elm is not useful for the general purposes of building, but from its durability in water it makes excellent

piles and planking for wet foundations. It is also used for water-works, such as pipes, pumps, and the like, and it is much used for coffins. The naves of wheels, the shells of blocks for tackle, the keels of ships, and sometimes the gunwales, are made of elm.

The colour of the heart-wood of elm is generally darker than that of oak, and of a redder brown. The sap-wood is of a yellowish or brownish white, with pores inclined to red. Elm is in general porous and cross-grained, sometimes very coarse-grained, and has no large septa. It has a peculiar odour. It twists and warps much in drying, and shrinks very much both in length and breadth. It is difficult to work, but is not liable to split, and bears the driving of bolts and nails better than any other timber. The timber of the English elm is generally esteemed the best; that of the wych elm is equally as good, but the Dutch elm is very inferior. Elm shrinks about $\frac{1}{44}$th of its width in seasoning.

The cohesive force of a square inch of elm varies from 6,070 to 13,200 pounds; and the weight of its modulus of elasticity for a square inch is about 1,343,000 pounds. The weight of a cubic foot dry is from 34 to 47 pounds; seasoned, from 36 to 50 pounds.

Representing	the mean	strength of oak by	100,	that of elm	is	82
,,	,,	stiffness of oak by	100,	,,	,,	78
,,	,,	toughness of oak by	100,	,,	,,	86

48. THE COMMON ACACIA, OR AMERICAN LOCUST TREE (*Robinia pseudo-acacia*), is a native of the mountains of America from Canada to Carolina. It is a beautiful tree, attains a considerable size, and is of very quick growth. The mean size of its trunk is 32 feet in length and 23 inches in diameter. The wood is much valued for its durability: some of the houses built by the first settlers in New England of this wood still con-

tinue firm and sound; and in posts, stakes, and pales, it is found to be one of the most durable kinds. It is adapted for any purpose to which oak is applied: it makes excellent tree-nails for ships, and is valuable for fencing.

The colour of the wood of the acacia is of a greenish yellow, with a slight tinge of red in the pores. Its structure is alternately nearly compact and very porous, which marks distinctly the annual rings. It has no large septa, and therefore no flowers. It has no sensible taste or odour in a dry state. It will require about the same degree of labour to work it as ash does.

The cohesive force of a square inch varies from 10,000 to 13,000 pounds; and the weight of a cubic foot, seasoned, is from 49 to 56 pounds. Its other properties, determined from young wood in an unseasoned state, are as under:—

WEIGHT OF THE MODULUS OF ELASTICITY FOR A SQUARE INCH, 1,687,500 POUNDS.

Representing the mean—

strength of oak by	100,	that of unseasoned acacia	is		95
stiffness of oak by	100,	,,	,,	,,	98
toughness of oak by	100,	,,	,,	,,	92

Hence in a dry state it will be superior to oak in these properties.

49. DIVISION II.—In the second division of the second class, the wood is uniformly porous; the distinction of the rings is chiefly owing to a difference between the colours of the sides of each ring. To this uniformity of texture may be referred the superiority of the woods in this division in retaining their original form; or, in other words, it is the reason they stand so well in work The woods of this division are very numerous, but many of them have little durability: only six are here

described; those are mahogany, walnut, teak, poona, African teak, and poplar.

50. MAHOGANY (*Swietonia mahogoni*) is a native of the West Indies, and the country round the Bay of Honduras in America. The tree is stated to be of very rapid growth, and its trunk often exceeds 40 feet in length, and 6 feet in diameter.

In a dry state mahogany is very durable, and not subject to worms. It does not last long when exposed to the weather. It is a kind of wood that would make excellent timbers for floors, roofs, &c.; but, on account of its price, its use is chiefly confined to furniture and doors for rooms; for which purposes it is the best material in use. It is sometimes used for some parts of window-frames and for sashes; but from its not standing the weather well, it is not so fit for these purposes. It has also been extensively used in the framing of machinery for cotton mills, &c.

The colour of mahogany is a red brown, of different shades, and various degrees of brightness; sometimes yellowish brown; often very much veined and mottled with darker shades of the same colour. The texture is uniform, and the annual rings are not very distinct. It has no large septa, but the smaller septa are often very visible, with pores between them; these pores are often filled with a white substance in the Jamaica wood, but generally empty in the Honduras kind. It has neither taste nor smell, shrinks very little, and warps or twists less than any other kind of wood. The variety called Spanish mahogany is imported from Cuba, and some other of the West Indian Islands, and in smaller logs than the Honduras. The size of the logs is in general about from 20 to 26 inches square, and about 10 feet in length. The Spanish mahogany is close-grained and hard, generally of a darker colour, and more beau-

tifully figured, than Honduras. It is much used for veneers and other works of the cabinet-maker, as well as for hand-rails of stairs.

The Honduras mahogany (sometimes called bay-wood) is imported in logs of a larger size, that is, from 2 to 4 feet square, and 12 or 14 feet in length; some planks have been got 6 or 7 feet wide. The grain of the Honduras kind is generally very open, and often irregular, with black or grey spots. It holds with glue better than any other wood.

The cohesive force of a square inch of Spanish mahogany is 7,560 pounds, and of Honduras mahogany 11,475 pounds. The weight of the modulus of elasticity of mahogany is 1,255,500 pounds for a square inch for Spanish, and 1,593,000 for Honduras. The weight of a cubic foot of mahogany is from 35 to 53 pounds.

Representing the—

strength of oak by	100, that of Span. mahog. is	67, of Hondr.	96
stiffness of oak by	100,	,,	73,	,,	93
toughness of oak by	100,	,,	61,	,,	99

51. THE WALNUT TREE (*Juglans regia*) is a native of Persia and the northern parts of China. The wood is very beautiful, and its colour superior to the red brown of mahogany. Walnut, on account of its scarcity, is hardly ever used for the purposes of building; indeed it is of too flexible a nature for beams, though it appears to have been used for that purpose by the ancients. The wood is durable, and not liable to be destroyed by worms; and it is much used for gun-stocks, from having the advantage of not producing sensible chemical action on iron or steel.

The hickory, or white walnut (*Juglans alba*), is a native of North America. It is a large tree, the trunk sometimes exceeding 3 feet in diameter. The wood of

young trees is extremely tough and flexible, making excellent handspikes.

The black Virginia walnut (*Juglans nigra*) is also a native of America, and is found from Pennsylvania to Florida. It is a large tree, and for furniture the wood is the most valuable of the walnut tree kind. It is of a fine grain, and beautifully veined, receiving an excellent polish. It is also durable, and not affected by worms. The heart-wood of walnut tree is of a greyish brown, with blackish brown pores, often much veined, with darker shades of the same colour; the sap-wood is greyish white. The colours are much brightened, and the veins rendered more distinct, by oiling. Its texture is not so uniform as that of mahogany, the pores being somewhat more thickly set on one side of the annual ring. It has no large septa or flowers. It has a slightly bitter taste when green, and a perceptible odour. It does not work so easily as mahogany, but may in general be brought to a smoother surface. It shrinks very little.

The cohesive force of a square inch of walnut varies from 5,360 to 8,130 pounds; its modulus of elasticity for a square inch is 837,000 pounds in a green state; the weight of a cubic foot varies from 40 to 48 pounds in a dry state.

Representing the—

strength of oak by	100,	that of	common	walnut is	74
stiffness of oak by	100,	,,	,,	,,	49
toughness of oak by	100,	,,	,,	,,	111

These properties were ascertained from a green specimen; the strength and stiffness would be greater in a dry state.

52. TEAK WOOD (*Tectona grandis*) is obtained from a tree which is a native of the mountainous parts of the Malabar and Coromandel coasts, as well as of Java,

Ceylon, and other parts of the East Indies. This tree is of rapid growth, and the trunk grows erect, to a vast height, with copious spreading branches. The wood is by far the most useful timber in India; it is light, easily worked, and though porous, it is strong and durable; it requires little seasoning, and shrinks very little; it affords tar of good quality, and is rather of an oily nature, therefore does not injure iron; and is the best wood in that country for ship timber, house carpentry, or any other work where strong and durable wood is required. Malabar teak is esteemed superior to any other in India, and is extensively used for ship-building at Bombay.

The cohesive force of teak wood varies from 13,000 to 15,000 pounds per square inch; the weight of its modulus of elasticity is 2,167,000 pounds per square inch, according to Mr. Barlow's experiments; and the weight of a cubic foot, seasoned, varies from 41 to 53 pounds.

Representing the	strength of oak by	100,	that of teak	will be	109
,,	stiffness of oak by	100,	,,	,,	126
,,	toughness of oak by	100,	,,	,,	94

From which it appears that it is much superior to oak in these properties, except in toughness; but it is to be remembered, that these proportions are drawn from two or three experiments on select specimens of teak; whereas those for oak are from a mean specimen, selected from pieces of oak of various qualities.

53. Poona Wood is brought from the East Indies. It very nearly resembles a dull-coloured and greyish specimen of mahogany; and would be useful for any purpose to which such kind of mahogany is applicable; besides having a greater degree of strength and stiffness compared with its weight. Poona is used for the decks, yards, and masts of ships, and it appears

well adapted for these purposes, both by its strength and lightness. Its texture is porous, but uniform; and the mean weight of a cubic foot in the dry state is 40·5 pounds.

The cohesive force of poona is from 10,000 to 14,700 pounds per square inch; the mean weight of the modulus of elasticity for a base of an inch square is 1,689,800 pounds.

54. TURTOSA, or AFRICAN TEAK, is imported from Sierra Leone. It is adapted to the same purposes as oak, and has been rather extensively used in ship-building for the navy. The colour is a moderately deep greyish brown. The texture is uniform, the annual rings not distinct, but the smaller septa are strong and numerous. It is dense, hard, and brittle. The taste is bitter, but the seasoned wood has no sensible smell.

The cohesive force of a square inch of turtosa is 17,200 pounds; and the weight of a cubic foot dry is 59·4 pounds; but it is variable from 58 to 61 pounds. The weight of the modulus of elasticity of turtosa is 1,728,000 pounds for a square inch A bar one foot long, and one inch square, supported at the ends, breaks with 954 pounds applied in the middle; and bends $\frac{1}{480}$ of its length, or one-fortieth of an inch, by a weight of 100 pounds.

55. THE POPLAR TREE (*Populus*) has five species common in England: the common white poplar, the black poplar, the aspen or trembling poplar, the abele or great white poplar, and the Lombardy poplar. The wood of the *aspen* lasts long when exposed to the weather, and most of the poplars prove very durable in a dry state.

The wood of most of the species makes very good flooring for bedrooms and places where there is not much wear, and it has the advantage of not catching

fire readily. The poplars produce woods sufficiently strong for light purposes, being soft, white, and easy to work, and well adapted for carving; but none of the species are fit for large timbers. There is not much difference in the wood of these species. The colour is of a yellowish or brownish white, one side of the annual rings being a little darker than the other, which renders the growth of each year visible. They are of an uniform texture, and are without the larger septa. The Lombardy, the black, and the common white poplar are the most esteemed. The Lombardy poplar is sometimes recommended for cheese-rooms and farm-houses in general, because neither mice nor mites will attack it. The cohesive force of a square inch of common white poplar is from 4,496 to 6,641 pounds, and the others will not differ much from it; the weight of the modulus of elasticity for a square inch is, for abele 1,134,000 pounds, and for Lombardy poplar 763,000 pounds; the weight of a cubic foot dry is, for abele 32 pounds, for common white poplar 33 pounds, for Lombardy poplar 24 pounds, for aspen and for black poplar 26 pounds.

Representing the—

strength of oak by 100,	that of abele is 86,	that of Lom. pop. is	50
stiffness of oak by 100,	,, ,, 66,	,, ,,	44
toughness of oak by 100,	,, ,, 112,	,, ,,	57

56. Division III.—In the third division of the second class, the woods are distinguished by the pores containing resinous matter. Some of the most useful and the most durable kinds of wood belong to this division. The cedars and the different species of pine belong to this division.

57. Cedar of Lebanon, or the Great Cedar.—(*Pinus cedrus*), is a cone-bearing tree, and an ever-green. It grows to a considerable size; the mean size

of the trunk is about 39 inches in diameter, and 50 feet in length. The wood is said to be very durable; the timber-work of the most celebrated temples of antiquity was in general executed in cedar, on account of its extreme durability.

It has no perceptible larger transverse septa; but when it is planed where it has been cut across the annual rings, the smaller septa present a very minute and beautiful dappled appearance. The general colour of cedar is a rich light yellowish brown; the annual rings distinct, each ring consisting of two parts, the one part harder, darker coloured, and more compact than the other. It is a resinous wood, and has a peculiar and powerful odour, with a slightly bitter taste, and is not subject to the worm. It is straight-grained, and easily worked, but readily splits.

The cohesive force of a square inch of cedar is 7,400 pounds; the weight of its modulus of elasticity for a square inch is 486,000 pounds; and the weight of a cubic foot seasoned is from 30·5 to 38 pounds.

Representing	the	strength of oak by	100,	that of cedar	is	62
"	"	stiffness of oak by	100,	"	"	28
"	"	toughness of oak by	100,	"	"	137

From these proportions it appears that it exceeds the oak in toughness, but is vastly inferior in stiffness and strength.

58. Red or Yellow Fir is the produce of the Scotch fir tree (*Pinus sylvestris*). It is a native of the hills of Scotland and other northern parts of Europe, and common in Russia, Denmark, Norway, Lapland, and Sweden. The great forests of Norway and Sweden consist almost entirely of Scotch fir and spruce fir. The Scotch fir is exported from thence in logs and deals, under the name of red-wood. Norway exports no trees

above 18 inches diameter, consequently there is much sap-wood; but the heart-wood is both stronger and more durable than that of larger trees from other situations. Riga exports a considerable quantity under the name of masts and spars; those pieces from 18 to 25 inches diameter are called *masts*, and are usually 70 or 80 feet in length; those of less than 18 inches diameter are called *spars*. Yellow deals and planks are imported from Stockholm, Gefle, Frederickshall, Christiana, and various other parts of Norway, Sweden, Prussia, and Russia.

Tar, pitch, and turpentine are obtained from the Scotch fir; and the tree is not injured by extracting these products when it has acquired a certain age; indeed some suppose the wood to be improved by it. It is the most durable of the pine species; and it was the opinion of Mr. Brindley that red Riga deal, or pine wood, would endure as long as oak in all situations.

Its lightness and stiffness render it superior to any other material for beams, girders, joists, rafters, and framing in general. It is also much used for masts and other parts of vessels. For joiners' work it is also much used, both for external and internal work, as it is more easily wrought, stands better, is nearly if not quite as durable, and is much cheaper than oak. The colour of the wood of the different varieties of Scotch fir differs considerably; it is generally of a reddish yellow, or a honey yellow, of various degrees of brightness. It consists in the section of alternate hard and soft circles; the one part of each annual ring being soft and light coloured, the other harder and dark coloured. It has no larger transverse septa, and it has a strong resinous odour and taste. It works easily when it does not abound in resin; and the foreign wood

shrinks about one-thirtieth part of its width in seasoning from the log.

The cohesive force of a square inch of—

Foreign timber varies from .	. 7,000 to 14,000 lbs
Mar Forest varies from . .	. 7,000 to 10,000 ,,
English growth varies from .	. 5,000 to 7,000 ,,

The weight of a cubic foot of—

Foreign fir, seasoned, varies from .	. 29 to 40 lbs.
English growth, seasoned, varies from	. 28 to 33 ,,
Mar Forest, seasoned, varies from .	. 38 ,,

The mean weight of the modulus of elasticity for a square inch of—

The foreign varieties of Scotch fir of a good quality is	1,687,000 lbs.
Mar Forest	. 845,000 ,,
English	. 951,000 ,,

The mean strength, stiffness, and toughness of oak being each represented by 100, those of the different varieties of Scotch fir will be represented by the numbers below :—

Strength of foreign timber 80, of Mar Forest ditto 61, of English grown ditto 60.
Stiffness of foreign timber 114, of Mar Forest ditto 49, of English grown ditto 55.
Toughness of foreign timber 56, of Mar Forest ditto 76, of English grown ditto 65.

59. WHITE FIR, OR DEAL, is the produce of different species of spruce fir; that from the north of Europe is produced by the Norway spruce (*Pinus abies*); but that from America is produced either by the white spruce (*Pinus alba*), or black spruce (*Pinus nigra*). It is imported in deals or planks. The Norway spruce is a native of mountains in various parts of Europe and the north of Asia. The forests of Norway afford it abundantly. A considerable quantity is imported from Christiana in deals and planks, which are esteemed the best white deals of any; not so much from the superior quality of the tree, as the regular thickness of the deals. The trees are usually cut into three lengths,

generally of about twelve feet each, and are afterwards cut into deals and planks by saw mills, each length yielding three deals or planks. A tree requires seventy or eighty years' growth before it arrives at perfection. White deals are also imported from Frederickstadt, Drontheim, and other ports in Norway; and from Gottenburg, Riga, and other of the Baltic ports.

White deal is very durable in a dry state, and is much used for internal joiners' work, and for furniture. It unites well with glue.

The American white spruce fir is a native of the high mountainous tracts in the colder parts of North America. The wood is not so resinous as that of the Norway spruce, and it is tougher, less heavy, and generally more liable to twist in drying. It is imported in deals and planks. The American black spruce fir is a native of the high mountainous tracts from the northern parts of Canada to Carolina. The black and white spruce are so named from the colour of the bark, the wood of both kinds being of the same colour. The black spruce is said to produce the best wood. The colour of spruce fir, or white deal, is yellowish or brownish white; the hard part of the annual ring a darker shade of the same colour; often has a silky lustre, especially in the American and British grown kinds. Each annual ring consists of two parts, the one hard, the other softer. The knots are generally very hard. The clear and straight-grained kinds are often tough, but not very difficult to work, and stand extremely well when properly seasoned: and they are often used for topmasts.

The cohesive force of—

A square inch of Christiana deal is from	8,000 to 12,000	lbs.
American white spruce . . .	8,000 to 10.000	„
British grown Norway spruce is about	8,000	„

The modulus of elasticity is 1,500,000 pounds for a square inch, taking the mean of the three kinds.

A cubic foot of—

Christiana deal weighs from	. 28 to 32 pounds when dry.	
American white spruce . .	. 29	" "
Norway spruce (British grown) .	. 34	" "

Representing the strength, stiffness, and hardness of oak, each by 100,

	Christiana deal.	American white spruce.	British grown Norway spruce.
The strength will be .	104	86	70
The stiffness . . .	104	72	81
The toughness . .	104	102	60

60. Weymouth Pine, or White Pine (*Pinus strobus*), is a native of North America, and is imported in large logs, often more than 2 feet square and 30 feet in length. It is one of the largest and most useful of the American pines, and makes excellent masts. The wood is light and soft, but is said to stand the weather tolerably well. In joiners' work the wood is much used for mouldings, and other work where clean straight-grained wood is desirable; but it is not durable, nor fit for large timbers, being very liable to take the dry rot. It has a peculiar odour.

The colour of the wood is a brownish yellow, the texture is more nearly uniform than that of any other of the pine species, and the annual rings not very distinct. It stands very well when seasoned, and is a very good kind of wood for moulds for casting from, and for some kinds of furniture; but its softness renders it unfit for many purposes. Its strength and other properties are given in a table on page 81.

61. Yellow Pine (*Pinus variabilis*) is a native of the pine forests from New England to Georgia, and the wood is much used for many of the carpenter's purposes, and for ship-building.

62. Pitch Pine (*Pinus resinosa*) is a native of Canada, and is remarkable for the abundance and fragrance of its resin, and for the beauty of its graining. It is a very heavy wood, and not very durable: it is also brittle when very dry. It is of a redder colour than the Scotch pine, feels sticky, and is difficult to plane. It has recently come largely into use for joinery and cabinet work.

63. Silver Fir (*Pinus picea*) is a native of the mountains of Siberia, Germany, and Switzerland, and is common in British plantations. It is a large tree, and produces the Strasburg turpentine of commerce. The wood is of a good quality, and much used on the Continent both for carpentry and ship-building. The harder fibres are of a yellow colour, compact, and resinous; the softer nearly white. Like the other kinds of fir, it is light and stiff, and does not bend much under a considerable load; consequently floors constructed of it remain permanently level. It is subject to the worm. It lasts longer in the air than in water, and it is therefore more fit for the upper parts of bridges than for piles and piers.

64. Cluster Pine (*Pinus pinaster*) is a native of the rocky mountainous parts of Europe, and is sometimes cultivated in British plantations. It is a larger tree than the Scotch pine, and produces both pitch and turpentine; and its wood is not of so red a colour The wood of the pinaster is more durable in water than in air, is of a finer grain than either the pine or silver fir, and contains less resin than either.

TABLE OF PROPERTIES OF THE PRECEDING SPECIES.

Kind.	Weight of a cubic foot.	Wt. of mod. of elasticity for a sq. in.	Cohesive force of a sq. in.	Stiffness.	Stren.	Toughness.
	Pounds.	Pounds.	Pounds.			
Weymouth pine	28¼	1,633,500	11,835	95	99	103
Yellow pine .	28					
Pitch pine .	41	1,252,200	9,796	73	82	92
Silver fir . .	25½					
Pinaster . .	25½					

In the fifth, sixth, and seventh columns, the stiffness, strength, and toughness of oak are each supposed to be represented by 100.

65. THE LARCH TREE has three species—one European and two American. The European larch tree (*Pinus larix*) is a native of the Alps of Switzerland, Italy, Germany, and Siberia. The variety from the Italian Alps is the most esteemed, and has been introduced to a considerable extent in the plantations of Britain. The mean size of the trunk is 45 feet in length and 33 inches in diameter. It is extremely durable in all situations, failing only where any other kind would fail. In posts, and other situations where it is exposed to damp and the weather, it is found to be very durable. In countries where larch abounds it is often used to cover buildings, which when first done are the natural colour of the wood, but in two or three years they become covered with resin, and as black as charcoal; the resin forms a kind of impenetrable varnish which effectually resists the weather. Larch is not attacked by common worms, and does not inflame readily. The larch is preferable to the pine, the pinaster, or the fir, for the construction of the arches of wooden bridges; and is useful for every purpose of building, whether external or internal; it

makes excellent ship-timber, masts, boats, posts, rails, and furniture. It is peculiarly adapted for flooring-boards in situations where there is much wear, and for staircases; in the latter, its fine colour, when rubbed with oil, is much preferable to that of the black oaken staircases to be seen in some old mansions. It is well adapted for doors, shutters, and the like; and from the beautiful colour of its wood when varnished, painting is not necessary.

The wood of the American black larch or Tamarack (*Pinus pendula*) is said to be nearly equal to that of the European larch; and that of the American red larch (*Pinus microcarpa*) is also of a very good quality; but they do not produce turpentine as the European kind.

The wood of the European larch is generally of a honey-yellow colour, the hard part of the annual rings of a redder cast; sometimes it is brownish white. In common with the other species of pine, each annual ring consists of a hard and soft part. It generally has a silky lustre, and its colour is browner than that of the Scotch pine, and it is much tougher. It is more difficult to work than Riga or Memel timber; but the surface is better when once it is obtained. It bears driving bolts and nails better than any other kind of the resinous woods. When it has become perfectly dry it stands well, but warps much in seasoning.

The cohesive force of a square inch is from 6,000 to 13,000 pounds; the modulus of elasticity for a square inch is 1,363,500 pounds; and the weight of a cubic foot of larch varies from 29 to 40 pounds when dry.

Representing the mean	strength of oak by	100,	that of larch	is	103
,, ,,	stiffness of oak by	100,	,,	,,	79
,, ,,	toughness of oak by	100,	,,	,,	134

Of the larch wood there are two very distinct kinds, differing much both in colour and quality; the one

being of a redder colour, harder, of a straighter grain, and more free from knots than the other, which is of a white colour and coarse grain. The white kind is the most common.

66. THE CEDAR TREE (*Juniperus*) has several species that produce valuable wood. There are also several other kinds of timber that are often called cedar. Thus a species of cypress is called white cedar in America; and the cedar used by the Japanese for building bridges, ships, houses, &c., is also a kind of cypress, which is a beautiful wood, and lasts long without decay. The *Juniperus oxycedrus* is a native of Spain, the South of France, and the Levant; it is usually called the brown-berried cedar. The wood of this species is supposed to have been the famous cedar of the ancients, so much celebrated for its durability. The Bermudian cedar (*Juniperus Bermudiana*), a native of Bermuda and the Bahama Islands, is another species that produces valuable timber for many purposes, such as internal joiners' work, furniture, and the like,

The red cedar, so well known from its being used in making black-lead pencils, is produced by the Virginian cedar (*Juniperus Virginiana*), a native of North America, the West India Islands, and Japan. The tree seldom exceeds 45 feet in height.

The wood of the red cedar is very durable, and is not attacked by worms or insects. It is used for drawers, wardrobes, and various kinds of furniture, for shipbuilding, and for pencils. Its colour is a brownish red, the sap-wood nearly white, texture nearly uniform: it is brittle, very light, and has a strong and peculiar odour, which renders it unfit to be employed in considerable quantities for internal work. Its specific gravity is ·650. The cohesive force is 4,875 pounds for a square inch.

67. Cowrie Wood is brought from New Zealand, and possesses many of the most esteemed qualities of the pine species; it is from a coniferous tree (the *Dammara Australis*), and contains a considerable quantity of resin. It appears to shrink very little, and bears exposure to the effects of the weather very well; the mean diameter of the trunk of the tree is said to be from 3 to 6 feet, and it is from 90 to 100 feet in height. It is a close, even, and fine-grained wood, of a very uniform texture; its colour is a light yellowish brown, the lustre silky, the annual rings marked by a line of a deeper tint of the same colour. It unites well with glue, and seems admirably adapted for internal joiners' work; it is used for masts and yards of ships. The cohesive force is from 9,600 to 10,960 pounds per square inch; the weight of the modulus of elasticity for a base an inch square is 1,982,400 pounds; and the weight of a cubic foot dry varies from 35 to 40¼ pounds.

CHAPTER II.

STRAINS ON BEAMS AND FRAMES, RESISTANCE OF TIMBER.

Section I.—Strains on Beams and Frames.

68. Application of the Laws of Mechanics.—In the present chapter our main aim will be to deduce from the principles and laws of mechanics, and the knowledge which experience and judicious inferences from it have given us concerning the strength of timber in relation to the strain laid on it, such maxims of construction as will unite economy with strength and efficacy.

This object is to be attained by a knowledge, 1st, of the strength of our materials, and of the absolute strain that is to be laid on them; 2ndly, of the modifications of this strain, by the place and direction in which it is exerted, and the changes that can be made by a proper disposition of the parts of our structure; and, 3rdly, having disposed every piece in such a manner as to derive the utmost advantage from its relative strength, we must know how to form the joints and other connections, in such a manner as to secure the advantages derived from this disposition.

69. The Theory of Carpentry is founded on two distinct portions of mechanical science—namely, a knowledge of the strains to which framings of timber are exposed, and a knowledge of their *relative* strength.

We shall therefore attempt to bring into one point of view the propositions of mechanical science that are more immediately applicable to the art of carpentry. From these propositions we hope to deduce such principles as shall enable an attentive reader to comprehend distinctly what is to be aimed at in framing timber, and how to attain this object with certainty: and we shall illustrate and confirm our principles by examples of pieces of carpentry which are acknowledged to be excellent in their kind.

70. THE COMPOSITION AND RESOLUTION OF FORCES is the most important proposition of general mechanics to the carpenter; and we beg our practical readers to endeavour to form very distinct conceptions of it, and to make it very familiar to their mind. When accommodated to their chief purposes, it may be thus expressed:

1st. If any body, or any part of a body, be at once pressed in the two directions AB, AC (Fig. 1), and if the intensity or force of those pressures be in the proportion of these two lines, the body is affected in the same manner as if it were pressed by a single force acting in the direction AD, which is the diagonal of the parallelogram ABDC formed upon the two lines, and whose intensity has the same proportion to the intensity of each of the other two that AD has to AB or AC.

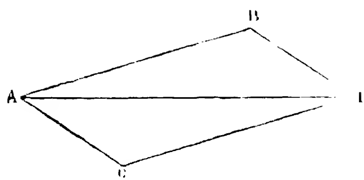


Fig. 1.

Such of our readers as have *studied* the laws of motion, know that this is fully demonstrated. We refer them to "Rudimentary Statics and Dynamics," by Baker, vol. 97 of the series, where it is treated at

some length. The practitioner in carpentry will get more useful confidence in the doctrine, if he will shut his book, and verify the theoretical demonstrations by actual experiments. They are remarkably easy and convincing. Therefore it is our request that the student, who is not so habitually acquainted with the subject, do not proceed further till he has made it quite familiar to his thoughts. Nothing is so conducive to this as the actual experiment; and since this only requires the trifling expense of two small pulleys and a few yards of whipcord, we hope that none of our practical readers will omit it.

2nd. Let the threads A *d*, AF *b*, and AE *c* (Fig. 2), have the weights *d*, *b*, and *c*, appended to them, and let two of the threads be laid over the pulleys F and E. By this apparatus the knot A will be drawn in the directions AB, AC, and AK. If the sum of the weights *b* and *c* be greater than the single weight *d*, the assemblage will of itself settle in a certain determined form; if you pull the knot A out of its place, it will always return to it again, and will rest in no other position. For example, if the three weights are equal, the threads will always make equal angles, of 120 degrees each, round the knot. If one of the weights be 3 pounds, another 4, and the third 5, the angle opposite to the thread stretched by 5 pounds will always be square, &c. When the knot A is thus in equilibrio, we must infer that the action of the weight *d*, in the direction A *d*, is in direct

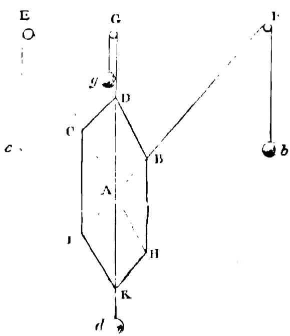


Fig. 2.

opposition to the combined action of *b*, in the direction AB, and of *c*, in the direction AC. Therefore, if we produce *d* A to any point D, and take AD to represent the magnitude of the force, or pressure exerted by the weight *d*, the pressures exerted on A by the weights *b* and *c*, in the directions AB, AC, are in fact equivalent to a pressure acting in the direction AD, whose intensity we have represented by AD. If we now measure off by a scale on AF and AE the lines AB and AC, having the same proportion to AD that the weights *b* and *c* have to the weight *d*, and if we draw DB and DC, we shall find DC to be equal and parallel to AB, and DB equal and parallel to AC; so that AD is the diagonal of a parallelogram ABDC. We shall find this always to be the case, whatever are the weights made use of; only we must take care that the weight which we cause to act without the intervention of a pulley be less than the sum of the other two: if any one of the weights exceeds the sum of the other two, it will prevail, and drag them along with it.

Now, since we know that the weight *d* would just balance an equal weight *g*, pulling directly upwards by the intervention of the pulley G; and since we see that it just balances the weights *b* and *c*, acting in the directions AB, AC, we must infer that the knot A is affected in the same manner by those two weights, or by the single weight *g*; and therefore, that *two pressures, acting in the directions, and with the intensities*, AB, AC, *are equivalent to a single pressure having the direction and proportion of* AD. In like manner, the pressures AB, AK, are equivalent to AH, which is equal and opposite to AC. Also AK and AC are equivalent to AI, which is equal and opposite to AB.

71. Combination of Pressures.—Suppose an upright beam BA (Fig. 3), pushed in the direction of its

length by a load B, and abutting on the ends of two beams AC, AD, which are firmly resisted at their extreme points C and D, which rest on two blocks, but are nowise joined to them: these two beams can resist

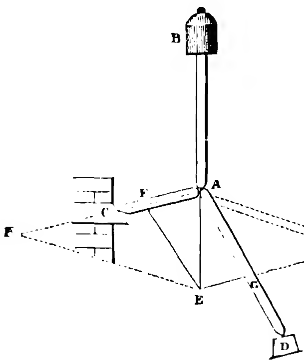


Fig. 3.

no way but in the directions CA, DA; and therefore the pressures which they sustain from the beam BA are in the directions AC, AD. We wish to know how much each sustains? Produce BA to E, taking AE from a scale of equal parts, to represent the number of tons or pounds by which BA is pressed. Draw EF and EG parallel to AD and AC; then AF, measured on the same scale, will give us the number of pounds by which AC is strained or crushed, and AG will give the strain on AD.

It deserves particular remark here, that the length of AC or AD has no influence on the strain, arising from the thrust of BA, while the directions remain the same. The effects, however, of this strain are modified by the length of the piece on which it is exerted. This strain compresses the beam, and will therefore compress a beam of double length twice as much. This may

change the form of the assemblage. If AC, for example, be very much shorter than AD, it will be much less compressed: the line CA will turn about the centre C, while DA will hardly change its position; and the angle CAD will grow more open, the point A sinking down. The student will find it of great consequence to pay very minute attention to this circumstance, and to be able to see clearly the change of shape which necessarily results from these mutual strains. He will see in this the cause of failure in many very great works. By thus changing shape, strains are often produced in places where there were none before, and frequently of the very worst kind, tending to break the beams across.

The dotted lines of this figure show another position of the beam AD. This makes a prodigious change, not only in the strain on AD′, but also in that on AC. Both of them are much increased; AG is almost doubled, and AF is four times greater than before. This addition was made to the figure, to show what enormous strains may be produced by a very moderate force AE, when it is exerted on a very obtuse angle.

The 4th and 5th Figures will assist the most unin-

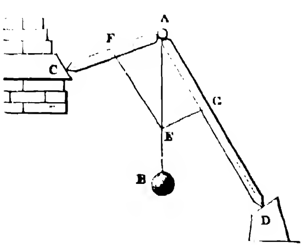


Fig. 4.

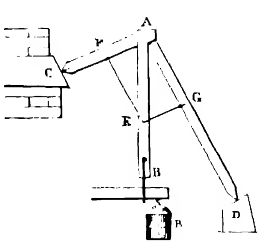


Fig. 5.

structed reader in conceiving how the very same strains AF, AG, are laid on these beams, by a weight simply

hanging from a billet resting on A, pressing hard on AD, and also leaning a little on AC; or by an upright piece AE, joggled on the two beams AC, AD, and performing the office of an ordinary king-post. The student will thus learn to call off his attention from the means by which the strains are produced, and learn to consider them abstractedly, merely as strains, in whatever situation he finds them, and from whatever cause they arise.

We presume that every reader will perceive, that the proportions of these strains will be precisely the same if everything be inverted, and each beam be drawn or pulled in the opposite direction. In the same way that we have substituted a rope and weight in Fig. 4, or a king-post in Fig. 5, for the loaded beam BA of Fig. 3, we might have substituted the framing of Fig. 6, which is a very usual practice. In this framing, the batten DA is stretched by a force AG, and the piece AC is compressed by a force AF. It is evident, that we may employ a rope, or an iron rod hooked on at D, in place of the batten DA, and the strains will be the same as before.

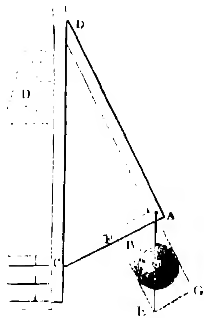


Fig. 6.

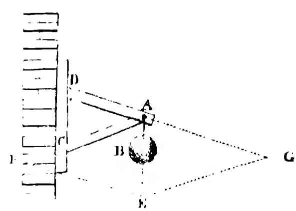


Fig. 7.

This seemingly simple matter is still full of instruction; and we hope that the well-informed reader will pardon us, though we dwell a little longer on it for the sake of the student in this art.

By changing the form of this framing, as in Fig. 7, we produce the same strains as in the disposition represented by the dotted lines in Fig. 3. The strains on both the battens AD, AC, are now greatly increased.

The same consequences result from an improper change of the position of AC. If it is placed as in Fig. 8, the strains on both are vastly increased. In short, the rule is general; that the more open we make the angle against which the push is exerted, the greater are the strains which are brought on the strutts or ties which form the sides of the angle.

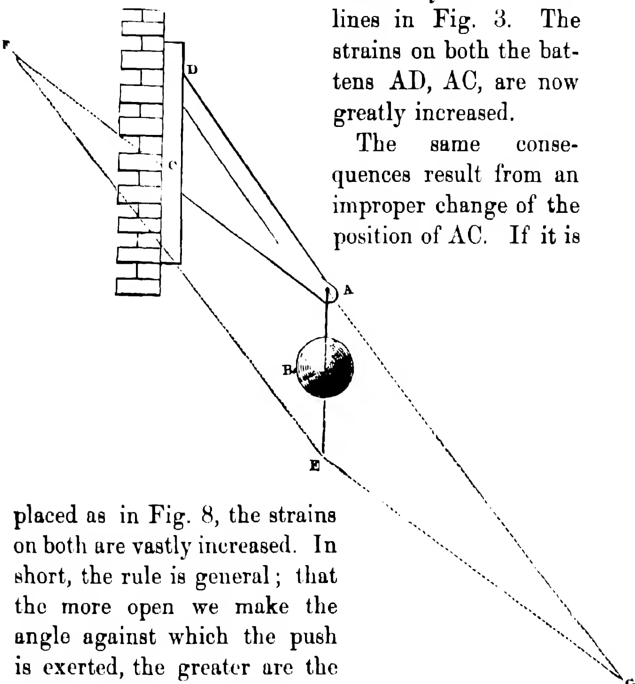


Fig. 8.

The reader may not readily conceive the piece AC of Fig. 8 as sustaining a compression; for the weight B appears to hang from AC as much as from AD. But his doubts will be removed by considering whether he could employ a rope in place of AC. He cannot: but AD may be exchanged for a rope. AC is therefore a *strutt*, and not a *tie*.

In Fig. 9, AD is again a strutt, butting on the block

D, and AC is a tie: and the batten AC may be replaced by a rope. While AD is compressed by the force AG, AC is stretched by the force AF.

If we give AC the position represented by the dotted line A*b*, the compression of AD is now AG′, and the force stretching A*b* is now AF′; both much

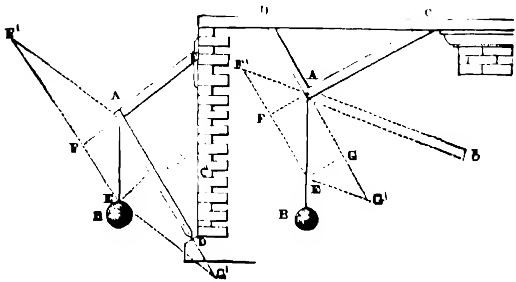


Fig. 9. Fig. 10.

greater than they were before. This disposition is analogous to Fig. 8, and to the dotted lines in Fig. 3. Nor will the student have any doubts of A*b* being on the stretch, if he consider whether AD can be replaced by a rope. It cannot, but A*b* may; and it is therefore not compressed, but stretched.

In Fig. 10, all the three pieces, AC, AD, and AB, are ties, on the stretch. This is the complete inversion of Fig 3; and the dotted position of A*b* induces the same changes in the forces AF′, AG′, as in Fig 3.

Thus have we gone over all the varieties which can happen in the bearings of three pieces on one point. All calculations about the strength of carpentry are reduced to this case: for when more ties or braces meet in a point (a thing that rarely happens), we reduce them to three, by substituting for any two the force which results from their combination, and then combining this with another; and so on.

The tyro must be particularly careful not to mistake the kind of strain that is exerted on any piece of the framing, and suppose a piece to be a brace which is really a tie. It is very easy to avoid all mistakes in this matter by the following rule, which has no exception.

72. THE DIRECTION OF THE STRAIN in which the piece acts is now to be noticed. Draw a line in that direction *from* the point on which the strain is exerted; and let its length (measured on some scale of equal parts) express the magnitude of this action in pounds, hundreds, or tons. From its *remote* extremity draw lines parallel to the pieces on which the strain is exerted. The line parallel to one piece will necessarily cut the other, or its direction produced: if it cut the piece itself, that piece is compressed by the strain, and it is performing the office of a strutt or brace: if it cut its direction produced, the piece is stretched, and it is a tie. In short, the strains on the pieces AC, AD, are to be estimated in the direction of the points F and G *from* the strained point A. Thus, in Fig 3, the upright piece BA, loaded with the weight B, presses the point A in the direction AE: so does the rope AB in the other figures, or the batten AB in Fig 5.

In general, if the straining piece is within the angle formed by the pieces which are strained, the strains which they sustain are of the opposite kind to that which it exerts. If it be pushing, they are drawing; but if it be within the angle formed by their directions produced, the strains which they sustain are of the same kind. All the three are either drawing or pressing. If the straining piece lie within the angle formed by one piece and the produced direction of the other, its own strain, whether compression or extension, is of the same kind with that of the most remote of the other two, and opposite to that of the nearest. Thus, in Fig. 9,

where AB is drawing, the remote piece AC is also drawing, while AD is pushing or resisting compression.

In all that has been said on this subject, we have not spoken of any joints. In the calculations with which we are occupied at present, the resistance of joints has no share; and we must not suppose that they exert any force which tends to prevent the angles from changing. The joints are supposed perfectly flexible, or to be like compass joints; the pin of which only keeps the pieces together when one or more of the pieces draws or pulls. The carpenter must always suppose them all compass joints, when he calculates the thrusts and draughts of the different pieces of his frames. The strains on joints, and their power to produce or balance them, are of a different kind, and require a very different examination.

73. Relation Between Angles and Strains.—Seeing that the angles which the pieces make with each other are of such importance to the magnitude and the proportion of the excited strains, it is proper to find out some way of readily and compendiously conceiving and expressing this analogy.

In general, the strain on any piece is proportional to the straining force. This is evident.

Secondly, the strain on any piece AC is proportional to the sine of the angle which the straining force makes with the other piece directly, and to the sine of the angle which the pieces make with each other inversely.

For it is plain, that the three pressures AE, AF, and AG, which are exerted at the point A, are in the proportion of the lines AE, AF, and FE (because FE is equal to AG). But because the sides of a triangle are proportional to the sines of the opposite angles, the strains are proportional to the sines of the angles AFE, AEF, and FAE. But the sine of AFE is the same with the sine of the angle CAD, which the two pieces

AC and AD make with each other; and the sine of AEF is the same with the sine of EAD, which the straining piece DA makes with the piece AC. Therefore we have this analogy, Sin. CAD : Sin. EAD = AE : AF, and

$AF = AE \times \frac{\text{Sin. EAD}}{\text{Sin. CAD}}$. The sines of angles are most conveniently conceived as decimal fractions of the radius, which is considered as unity. Thus, *Sin.* 30° is the same thing with 0·5, or $\frac{1}{2}$; and so of others. Therefore, to find the strain on AC, arising from any load AE acting in the direction AE, multiply AE by the sine of EAD, and divide the product by the sine of CAD.

This rule shows how great the strains must be when the angle CAD becomes very open, approaching to 180 degrees. But when the angle CAD becomes very small, its sine (which is our divisor) is also very small; and we should expect a very great quotient in this case also. But we must observe, that in this case the sine of EAD is also very small; and this is our multiplier. In such a case, the quotient cannot exceed unity.

But it is unnecessary to consider the calculation by the tables of sines more particularly. The angles are seldom known any otherwise but by drawing the figure of the frame of carpentry. In this case we can always obtain the measures of the strains from the same scale, with equal accuracy, by drawing the parallelogram AFCG.

74. Strains Represented by Lines.—Hitherto we have considered the strains excited at A only as they affect the pieces on which they are exerted. But the pieces, in order to sustain, or be subject to any strain, must be supported at their ends C and D; and we may consider them as mere intermediums, by which these strains are made to act on these points of support: therefore AF and AG are also measures of the forces

which press or pull at C and D. Thus we learn the supports which must be found for these points. These may be infinitely various. We shall attend only to such as somehow depend on the framing itself.

Such a structure as Fig. 11 very frequently occurs, where a beam BA is strongly pressed to the end of another beam AD, which is prevented from yielding, both because it lies on another beam HD, and because its end D is hindered from sliding backwards. It is indifferent from what this pressure arises; we have represented it as owing to a weight hung on at B, while B is withheld from yielding by a rod or rope hooked to the wall. The beam AD may be supposed at full liberty to exert all its pressure on D, as if it were supported on rollers lodged in the beam HD; but the loaded beam BA presses both on the beam AD and on HD. We wish only to know what strain is borne by AD?

All bodies act on each other in the direction perpendicular to their touching surfaces; therefore the support given by HD is in a direction perpendicular to it.

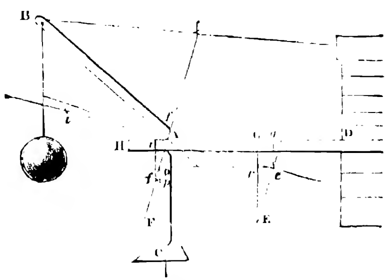


Fig. 11.

We may therefore supply its place at A by a beam AC, perpendicular to HD, and firmly supported at C. In this case, therefore, we may take AE as before, to repre-

sent the pressure exerted by the loaded beam, and draw EG perpendicular to AD, and EF parallel to it, meeting the perpendicular AC in F. Then AG is the strain compressing AD, and AF is the pressure on the beam HD.

75. Form of Joints. — It may be thought that, since we assume as a principle that the mutual pressures of solid bodies are exerted perpendicular to their touching surfaces, this balance of pressures, in framings of timbers, depends on the directions of their butting joints; but it does not, as will readily appear by considering the present case. Let the joint or abutment of the two pieces BA, AD, be mitred, in the usual manner, in the direction *f* A *f'*. Therefore, if A *e* be drawn perpendicular to A *f*, it will be the direction of the actual pressure exerted by the loaded beam BA on the beam AD. But the reaction of AD, in the opposite direction A *t*, will not balance the pressure of BA; because it is not in the direction precisely opposite. BA will therefore slide along the joint, and press on the beam HD. AE represents the load on the mitre joint A. Draw E *e* perpendicular to A *e*, and E *f* parallel to it. The pressure AE will be balanced by the reactions *e* A and *f* A; or, the pressure AE produces the pressures A *e* and A *f*; of which A *f* must be resisted by the beam HD, and A *e* by the beam AD. The pressure A *f* not being perpendicular to HD, cannot be fully resisted by it; because (by our assumed principle) it reacts only in a direction perpendicular to its surface. Therefore draw *f p*, *f i* parallel to HD, and perpendicular to it. The pressure A *f* will be resisted by HD with the force *p* A; but there is required another force *i* A, to prevent the beam BA from slipping outwards. This must be furnished by the reaction of the beam DA. In like manner, the other force A *e* cannot be fully resisted by the beam AD, or rather by the prop

D, acting by the intervention of the beam: for the action of that prop is exerted through the beam in the direction DA. The beam AD, therefore, is pressed to the beam HD by the force A *e*, as well as by A *f*. To find what this pressure on HD is, draw *e g* perpendicular to HD, and *e o* parallel to it, cutting EG in *r*. The forces *g* A and *o* A will resist and balance A *e*.

Thus we see, that the two forces A *e* and A *f*, which are equivalent to AE, are equivalent also to A *p*, A *i*, A *o*, and A *g*. But because A *f* and *e* E are equal and parallel, and E *r* and *f i* are also parallel, as also *e r* and *f p*, it is evident that *i f* is equal to *r* E, or to *o* F, and *i* A is equal *r e*, or to G *g*. Therefore the four forces A *g*, A *o*, A *p*, A *i*, are equal to AG and AF. Consequently AG is the compression of the beam AD, or the force pressing it on D, and AF is the force pressing it on the beam HD. The proportion of these pressures, therefore, is not affected by the form of the joint.

This remark is important; for many carpenters think the form and direction of the butting joint of great importance; and even the theorist, by not prosecuting the general principle through *all* its consequences, may be led into an error. The form of the joint is of no importance, in as far as it affects the strains in the direction of the beams; but it is often of great consequence, in respect to its own firmness, and the effect it may have in bruising the piece on which it acts, or being crippled by it.

76. Application to a Roof.—The same compression of AB, and the same thrust on the point D by the intervention of AD, will obtain, in whatever way the original pressure on the end A is produced. Thus, supposing that a cord is made fast at A, and pulled in the direction AE, and with the same force, the beam AD will be equally compressed, and the prop D must react with the same force.

But it often happens that the obliquity of the pressure on AD, instead of compressing it, stretches it; and we desire to know what tension it sustains. Of this we have a familiar example in a common roof. Let the two rafters AC, AD (Fig. 12), press on the tie-beam DC. We may suppose the whole weight to press vertically on the ridge A, as if a weight B were hung on there. We may represent this weight by the

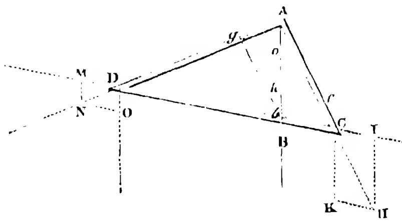


Fig. 12.

portion A *b* of the vertical or plumb line, intercepted between the ridge and the beam. Then drawing *b f* and *b g* parallel to AD and AC, A *g* and A *f* will represent the pressures on AC and AD. Produce AC till CH be equal to A *f*. The point C is forced out in this direction, and with a force represented by this line. As this force is not perpendicularly across the beam, it evidently stretches it; and this extending force must be withstood by an equal force pulling it in the opposite direction. This must arise from a similar oblique thrust of the opposite rafter on the other end D. We concern ourselves only with this extension at present; but we see that the cohesion of the beam does nothing but supply the balance to the extending forces. It must still be supported externally, that it *may resist*, and, by resisting obliquely, be stretched. The points C and D are supported on the walls, which they press in the directions CK and DO, parallel to A *b*. If we

draw HK parallel to DC, and HI parallel to CK (that is, to A *b*), meeting DC produced in I, it follows from the composition of forces, that the point C would be supported by the two forces KC and IC. In like manner, making DN $=$ A *g*, and completing the parallelogram DMNO, the point D would be supported by the forces OD and MD. If we draw *g o* and *f k* parallel to DC, it is plain that they are equal to NO and CK, while A *o* and A *k* are equal to DO and CK, and A *b* is equal to the sum of DO and CK (because it is equal to A *o* + A *k*). The weight of the roof is equal to its vertical pressure on the walls.

Thus we see, that while a pressure on A, in the direction A *b*, produces the strains A *f* and A *g*, on the pieces AC and AD, it also excites a strain CI or DM in the piece DC. And this completes the mechanism of a frame; for all derive their efficacy from the triangles of which they are composed, as will appear more clearly as we proceed.

77. Frame of Carpentry.—But there is more to be learned from this. The consideration of the strains on the two pieces AD and AC, by the action of a force at A, only showed them as the means of propagating the same strains in their own direction to the points of support. But, by adding the strains exerted in DC, we see that the frame becomes an intermedium, by which exertions may be made on other bodies, in certain directions and proportions; so that this frame may become part of a more complicated one, and, as it were, an element of its constitution. It is worth while to ascertain the proportion of the pressures CK and DO, which are thus exerted on the walls. The similarity of triangles gives the following analogies:

$$\text{DO} : \text{DM} = \text{A}b : b\text{D}.$$
$$\text{CI, or DM} : \text{CK} = \text{C}b : \text{A}b$$
$$\text{Therefore DO} : \text{CK} = \text{C}b : b\text{D}$$

Or, *the pressures on the points* C *and* D, *in the direction of the straining force,* A *b, are reciprocally proportional to the portions of* DC *intercepted by* A *b.*

Also, since A *b* is $=$ DO $+$ CK, we have

$$A\,b : CK = C\,b + b\,D \text{ (or } CD) : b\,D, \text{ and}$$
$$A\,b : DO = CD : b\,C.$$

In general, any two of the three parallel forces A *b*, DO, CK, are to each other in the reciprocal proportion of the parts of CD, intercepted between their directions and the direction of the third.

And this explains a still more important office of the frame ADC. If one of the points, such as D, be supported, an external power acting at A, in the direction A *b*, with an intensity which may be measured by A *b*, may be set in equilibrio, with another acting at C, in the direction CL, opposite to CK, or A *b*, and with an intensity represented by CK: for since the pressure CH is partly withstood by the force IC, or the firmness of the beam DC supported at D, the force KC will complete the balance. When we do not attend to the support at D, we conceive the force A *b* to be balanced by KC, or KC to be balanced by A *b*. And, in like manner, we may neglect the support or force acting at A, and consider the force DO as balanced by CK.

Thus our frame becomes a lever, and we are able to trace the interior mechanical procedure which gives it its efficacy: it is by the intervention of the forces of cohesion, which connect the points to which the external forces are applied with the supported point or fulcrum, and with each other.

These strains or pressures A *b*, DO, and CK, not being in the directions of the beams, may be called *transverse*. We see that by their means a frame of carpentry may be considered as a solid body: but the

example which brought this to our view is too limited for explaining the efficacy which may be given to such constructions. We shall therefore give a general proposition, which will more distinctly explain the procedure of nature, and enable us to trace the strains as they are propagated through all the parts of the most complicated framing, finally producing the exertion of its most distant points.

78. STRAINS IN FRAMING.—We presume that the learner is now pretty well habituated to the conception of the strains as they are propagated along the lines joining the points of a frame, and we shall therefore employ a very simple figure.

Let the strong lines ACBD (Fig. 13) represent a frame of carpentry. Suppose that it is pulled at the

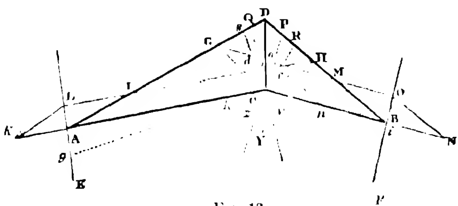


Fig. 13.

point A by a force acting in the direction AE, but that it rests on a fixed point C, and that the other extreme point B is held back by a power which resists in the direction BF: it is required to determine the proportion of the strains excited in its different parts, the proportion of the external pressures at A and B, and the pressure which is produced on the obstacle or fulcrum C?

It is evident that each of the external forces at A and B tend one way, or to one side of the frame, and that each would cause it to turn round C if the other

did not prevent it; and that if, notwithstanding their action, it is turned neither way, the forces in actual exertion are in equilibrio by the intervention of the frame. It is no less evident that these forces concur in pressing the frame on the prop C. Therefore, if the piece CD were away, and if the joints C and D be perfectly flexible, the pieces CA, CB would be turned round the prop C, and the pieces AD, DB would also turn with them, and the whole frame change its form. This shows, by the way, and we desire it to be carefully kept in mind, that the firmness or stiffness of framing depends entirely on the triangles bounded by beams which are contained in it. An open quadrilateral may always change its shape, the sides revolving round the angles. A quadrilateral may have an infinity of forms, without any change of its sides, by merely pushing two opposite angles towards each other, or drawing them asunder. But when the three sides of a triangle are determined, its shape is also invariably determined; and if two angles be held fast, the third cannot be moved. It is thus that, by inserting the bar CD, the figure becomes unchangeable; and any attempt to change it by applying a force to an angle A, immediately excites forces of attraction or repulsion between the particles of the stuff which forms its sides. Thus it happens, in the present instance, that a change of shape is prevented by the bar CD. The power at A presses its end against the prop; and in doing this it puts the bar AD on the stretch, and also the bar DB. Their places might therefore be supplied by cords or metal wires. Hence it is evident that DC is compressed, as is also AC; and for the same reason, CB is also in a state of compression; for either A or B may be considered as the point that is impelled or withheld. Therefore DA and DB are stretched, and are resisting

with attractive forces. AC and CB are compressed, and are resisting with repulsive forces. DC is also acting with repulsive forces, being compressed in like manner: and thus the support of the prop, combined with the firmness of DC, puts the frame ADBC into the condition of the two frames in Fig. 8 and Fig. 9. Therefore the external force at A is really in equilibrio with an attracting force acting in the direction AD, and a repulsive force acting in the direction AK. And since all the connecting forces are mutual and equal, the point D is pulled or drawn in the direction DA. The condition of the point B is similar to that of A, and D is also drawn in the direction DB. Thus the point D, being urged by the forces in the directions DA and DB, presses the beam DC on the prop, and the prop resists in the opposite direction. Therefore the line DC is the diagonal of the parallelogram, whose sides have the proportion of the forces which connect D with A and B. This is the principle on which the rest of our investigation proceeds. We may take DC as the representation and measure of their joint effect. Therefore draw CH, CG, parallel to DA, DB, and HL, GO, cutting AE, BF in L and O, and DA, DB in I and M. Complete the parallelograms ILKA, MONB. Then DG and AI are the equal and opposite forces which connect A and D; for GD=CH,=AI. In like manner DH and BM are the forces which connect D and B.

The external force at A is in immediate equilibrio with the combined forces, connecting A with D and with C. AI is one of them: therefore AK is the other; and AL is the compound force with which the external force at A is in immediate equilibrium. This external force is therefore equal and opposite to BO; and AL is to BO as the external force at A to the external force at B. The prop C resists with forces

equal to those which are propagated to it from the points D, A, and B. Therefore it resists with forces CH, CG, equal and opposite to DG, DH; and it resists the compressions KA, NB, with equal and opposite forces C *k*, C *n*. Draw *k l*, *n o* parallel to AD, BD, and draw C *l* Q, C *o* P: it is plain that *k* C H *l* is a parallelogram equal to KAIL, and that C *l* is equal to AL. In like manner C *o* is equal to BO. Now the forces C *k*, CH, exerted by the prop, compose the force C *l*; and C *n*, CG compose the force C *o*. These two forces C *l*, C *o* are equal and parallel to AL and BO; and therefore they are equal and opposite to the external forces acting at A and B. But they are (primitively) equal and opposite to the pressures (or at least the compounds of the pressures) exerted on the prop, by the forces propagated to C from A, D, and B. Therefore the pressures exerted on the prop are the same as if the external forces were applied there in the same directions as they are applied to A and B. Now, if we make CV, CZ equal to C *l* and C *o*, and complete the parallelogram CVYZ, it is plain that the force YC is in equilibrio with *l* C and *o* C. Therefore the pressures at A, C, and B are such as would balance if applied to one point.

Lastly, in order to determine their proportions, draw CS and CR perpendicular to DA and DB. Also draw A *d*, B *f* perpendicular to CQ and CP; and draw C *g*, C *i* perpendicular to AE, BF.

The triangles CPR and BP *f* are similar, having a common angle P, and a right angle at R and *f*.

In like manner the triangles CQS and AQ *d* are similar. Also the triangles CHR, CGS are similar, by reason of the equal angles at H and G, and the right angles at R and S. Hence we obtain the following analogies:

$$
\begin{array}{ll}
C\,o : C\,P = O\,n : P\,B, & = C\,G : P\,B \\
C\,P : C\,R = & P\,B : f\,B \\
C\,R : C\,S = & C\,H : C\,G \\
C\,S : C\,Q = & A\,d : A\,Q \\
C\,Q : C\,l = A\,Q : K\,l, & = A\,Q : C\,H.
\end{array}
$$

Therefore, by equality,

$$
\begin{array}{ll}
C\,o : C\,l = & A\,d : f\,B, \text{ or} \\
B\,O : A\,L = & C\,g : C\,i.
\end{array}
$$

That is, the external forces are reciprocally proportional to the perpendiculars drawn from the prop on the lines of their direction.

This proposition (sufficiently general for our purpose) is fertile in consequences, and furnishes many useful instructions to the student. The strains LA, OB, CY, that are excited, occur in many, we may say in all, framings of carpentry, whether for edifices or engines, and are the sources of their efficacy. It is also evident, that the doctrine of the transverse strength of timber is contained in this proposition; for every piece of timber may be considered as an assemblage of parts, connected by forces which act in the direction of the lines which join the strained points on the matter that lies between those points, and also act on the rest of the matter, exciting those lateral forces which produce the inflexibility of the whole.

Thus it appears that this proposition contains the principles which direct the carpenter to frame the most powerful levers; to secure uprights by shores or braces, or by ties and ropes; to secure scaffoldings for the erection of spires, and many other most delicate problems of his art. He also learns, from this proposition, how to ascertain the strains that are produced, without his intention, by pieces which he intended for other offices, and which, by their transverse action, put his work in hazard. In short, this proposition is the key to the science of his art.

79. MAXWELL'S DIAGRAM OF STRESS.—This method enables any one who has had practice in ruling parallel lines, and the use of scales and compasses, to measure off accurately all the various strains to which each part of a truss or assemblage of beams is subject; so as to be able to determine what strength ought to be given to each part of the framework. The principle itself is explained in Tarn's "Science of Building" (page 3), and an example of its application is also worked out (page 104); we shall, however, give an example of its application to a king-post roof truss in which the wind is supposed to act as a strain upon one side only at a time, an hypothesis which is more nearly correct than if sup-

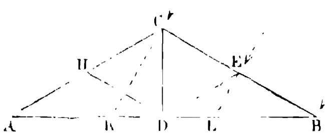


Fig. 14.

posed to act as a vertical strain. Let Figure 14 represent the truss having a span of 20 feet, the rafters inclined to the tie-beam at 30°, and the trusses supposed 10 feet from centre to centre; the purlins will throw the weight on the points A, H, C, E, and B. Assume that 20 lbs. per square foot, measured on the slope, is the weight of the roof timbers (except tie-beam and ceiling) together with the covering and snow, then 4,600 lbs. is the weight borne by each truss; the weight of tie-beam and ceiling 2,400 lbs. Let the force of the wind be 40 lbs. per foot acting perpendicularly to the slope of the rafters on one side only; this will amount to 4,600 lbs. uniformly distributed over one side of the roof and at right angles thereto. Now when a continuous beam is uniformly loaded and supported at the centre and two

ends, $\frac{3}{16}$ths of the load is borne at each end and $\frac{5}{8}$ths at the middle. Hence the loads at A and B are $\frac{3}{32} \times 4,600 = 430$ lbs.; at C, $\frac{6}{32} \times 4,600 = 860$ lbs.; at E and H, $\frac{5}{16} \times 4,600 = 1,440$ lbs. Also the weight of tie-beam and ceiling produces a load of $\frac{3}{16} \times 2,400 = 450$ lbs. at A and B, and of $\frac{5}{8} \times 2400 = 1,500$ lbs. at D. The force of the wind on the right hand side produces at B and C a pressure of $\frac{3}{16} \times 4,600 = 860$ lbs., and at E $\frac{5}{8} \times 4,600 = 2,880$ lbs.

We have now to draw two stress diagrams, one showing the stresses arising from the vertical forces, and the other those produced by the pressure of the wind acting at right angles to one side of the roof.

Half the total weight of the roof is of course borne at each end A and B, and amounts to 3,500 lbs., which is the reaction at A and B.

To construct the diagram (Fig. 15) for vertical forces, draw a vertical line $c\,b$, and measure $a\,b$ representing on any scale 430 lbs., the pressure at A or B; take $b\,c$ equal to 3,500 on the same scale; draw $c\,d$ parallel to AB, and $a\,d$ parallel to AC. Measure $a\,e$ equal to 1,440 lbs., the vertical pressure at E or H, draw $e\,f$ parallel to AC, and $d\,f$ parallel to DH. Take $e\,g$ equal to 860 lbs., the load at C, and draw $g\,h$ parallel to DH. Then $c\,d$, $d\,a$ represent in direction and magnitude the stresses in AD, AH respectively, the former in tension and the latter in compression; $d\,f$ and $f\,e$, those in HD, HC, both in compression; $f\,h$, the tension in the king-post. Measuring these lines by the scale, we find $c\,d = 4,500$ lbs. the tension in AB; $d\,a = 5,250$ lbs. the

compression in AH or BE; $df = 1{,}400$ lbs. the compression in HD or ED; $fe = 3{,}800$ lbs. the compression

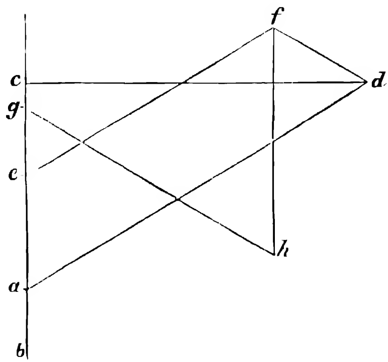


Fig. 15.

in HC or EC; $fh = 2{,}900$ lbs., the tension in the king-post CD.

We have now to find the stresses arising from the wind acting in the direction of the arrows at B, E, and C, at right angles to BC. The pressure at C is 860 lbs., and produces a reaction at B equal to $860 \times \frac{AK}{AB}$, or 290 lbs.; also a reaction at A of $860 \times \frac{BK}{AB}$, or 570 lbs. The pressure at E is 2,880 lbs. and produces a reaction at B of 2,880 lbs. $\times \frac{AL}{AB}$, or 1,900 lbs.; and a reaction at A of $2{,}880 \times \frac{BL}{AB}$, or 970 lbs. Therefore the total reaction at B is 860 + 290 + 1,900, or 3,050 lbs; and at A it is 570 + 970, or 1,540 lbs. Draw a line $q\,l$ (Fig. 16) parallel to CK, and take $k\,l$ to represent 860 lbs., $l\,m$ to represent, on the same scale, 3,050 lbs.; draw $m\,n$ parallel to AB, and $k\,n$ to BC; then $m\,n$ represents the tensile strain in AB, $n\,k$ the compressive strain in BE.

Take $k\,o$ equal to 2,880 lbs., and draw $o\,p$ parallel to EC, $p\,n$ parallel to ED; then $o\,p$ represents the compression produced by the force of the wind in EC, and $p\,n$ that in ED. Draw the vertical $p\,r$, which is the strain in the king-post; and draw $r\,q$ parallel to AC, which is the compression produce in that rafter. Measuring by scale, we find $m\,n$ is 4,400 lbs., the tension in the tie-beam; $n\,k$ is 3,800 lbs., the compression in BE; $o\,p$ is 2,150 lbs., the compression in EC; $p\,n$ is 3,330 lbs., the

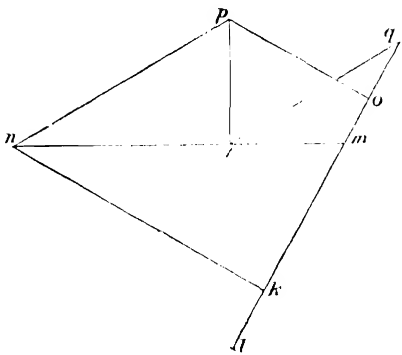


Fig. 16.

compression in ED; $p\,r$ is 1,650 lbs., the tension in the king-post CD; $r\,p$ is 2,660 lbs., the compression in AC.

Collecting the strains obtained by the two diagrams, we have,

Tension in tie-beam	= 4,500 + 4,400 =	8,900 lbs.
,, ,, king-post	= 2,900 + 1,650 =	4,550 ,,
Compression in rafter	= 5,250 + 3,800 =	9,050 ,,
,, ,, strut	= 1,400 + 3,330 =	4,730 ,,

80. Scantlings of Roof Timbers.—We can now, by applying the rules given elsewhere for the strength of timber, find the scantlings required in the case before us.

Suppose the framing to be of Memel fir, the safe

tensile strain of which is 1,200 lbs. per square inch, then the tie-beam need only have a transverse section of $7\frac{1}{2}$ square inches, and the king-post of $3\frac{3}{4}$ square inches; as, however, each half of the tie-beam has to carry a distributed load of 1,200 lbs., the tie-beam, if made 7 inches deep, must be 2 inches thick. To find the strength of the rafters and struts, we must consider them as long pillars, and use the formula (page 129)—

$$W = 2{,}500 \times \frac{d^4}{l^2},$$

which is the safe load when d is the diameter in inches and l the length in feet. Putting $l = 6$ feet, we find the rafters must have a scantling of $3\frac{3}{4}$ inches square, and the struts about $3\frac{1}{4}$ inches square. In these dimensions, however, no allowance is made for cutting away portions of the timber for mortises or for defective portions of the wood; and Tredgold's scantlings for such a roof are as follows:—Tie-beam $9\frac{1}{2} \times 4$, king-post 4×3, rafters 4×4, braces $3\frac{1}{2} \times 2$; in which the strength of the tie-beam is excessive, whilst that of the braces is rather deficient; a better arrangement would be, tie-beam 7×3, king-post $2\frac{1}{2} \times 3$, rafters $4\frac{1}{2} \times 3$, braces $3\frac{1}{2} \times 3$.

Some examples of the application of this method of calculating strains are given in a paper read at the Royal Institute of British Architects (April 22, 1872), by Capt. Seddon, R.E.; and also in Ranken's "Strains in Trusses." The reader is also referred to a treatise on Graphic and Analytic Statics, by R. H. Graham, C.E. (Crosby Lockwood & Co., 1883).

Section II.—Resistance of Timber.

81. The Laws of the Resistance of Timber depend on the manner in which the pieces are strained, and may be divided into three kinds:

First, When the force tends to pull the piece asunder in the direction of its length, or the *resistance to tension.*

Secondly, When the force tends to break the piece across, or the *resistance to cross strains.*

Thirdly, When the force tends to compress the body in the direction of its length, or the *resistance to compression.*

Stiffness is that property of bodies by which they resist flexure or bending. *Strength* is that by which they resist fracture or breaking. This distinction must be carefully attended to, because the laws of strength and stiffness are not the same. For instance, the stiffness of a cylinder, exposed to a cross strain, increases as the fourth power of the diameter, but the strength increases only as the cube of the diameter. If the diameter of a cylinder be doubled, its stiffness will be sixteen times as great, but its strength will only be increased eight times.

In those members of carpentry that are unavoidably subject to cross strain, the comparative stiffness is of much greater importance than the comparative strength, as timbers are seldom exposed to strains that break them.

All bodies may be extended or compressed; and within the limits useful in practice, the extension or compression is directly as the force producing it: that is, if a force of 100 pounds produce an extension of one-tenth of an inch, 200 pounds will produce an extension of two-tenths of an inch, and so on. It is on the truth of this principle that the greater part of the following inquiry depends; and it has been found by experiment to be perfectly regular to an extent which embraces all useful cases.

82. RESISTANCE TO TENSION.—It is apparently the

most simple case of extension when a piece is pulled in the direction of its length; but this simplicity is confined to the case when the line of strain corresponds exactly with the centre of the section, otherwise it is the most complicated, or at least the most difficult to manage in a theoretical point of view. When a beam is strained in the direction of its length, the extension will obviously be directly proportional to the straining weight, and to the length of the piece; and inversely proportional to its area, or to the product of its breadth and depth when the piece is rectangular.

The strength to resist a weight that will produce fracture in the direction of its length is as the area of the section. Consequently, if we multiply the area of the section in inches, by the weight that will tear asunder a bar an inch square of the same kind of wood, the product will be the weight in pounds the piece will just support; but the greatest constant load any piece should be allowed to sustain ought not to exceed one fourth of this. The same rule applies to the cohesion of timber when it is pulled asunder at right angles to the direction of the fibres.

83. Tables of Cohesive Force.—The following tables contain the results of the chief experiments that have been made on the direct strength:—

Kind of wood, and spec. grav.	Cohesion of a sq. in. in lbs.	Kind of wood, and spec. grav.	Cohesion of a sq. in. in lbs.
Oak, English ·7	19,800	Beech . . .	17,709
Oak . . .	17,300	Ditto . . .	11,500
Ditto . . .	13,950		
Ditto, dry } from .	12,000	Alder . . .	14,186
English } to .	8,889		
Ditto, black bog . . } ·67	7,700	Sycamore . ·69	13,000
		Chestnut, Spanish	13,300
Beech . . ·72	22,000	Ditto . . ·61	10,500

Kind of wood, and spec. grav.	Cohesion of a sq. in. in lbs.	Kind of wood, and spec. grav.	Cohesion of a sq. in. in lbs.
Ash . { from	17,850	Poplar. . ·36	7,200
Ash . { to .	16,784	Ditto . { from	6,641
Ditto . . ·84	16,700	Ditto . { to .	4,596
Ditto . . .	12,000		
Elm . . ·69	14,400	Norway pine ·66	14,300
Ditto . . .	13,489	Petersburg do. ·49	13,300
Acacia . . .	20,582	Fir . { from	13,448
Ditto . . ·85	16,000	Fir . { to .	11,000
Mahogany . ·87	21,800	Ditto . . .	8,506
Ditto . . .	8,000	Pitch pine . .	7,818
Walnut . .	8,130	Norway pine .	7,287
Ditto . . ·59	7,800	Larch . . .	10,220
Teak . . .	15,000	Ditto . . ·57	8,900
Ditto, old . ·53	8,200	Cedar . . ·54	11,400
		Ditto . . .	4,973
		Lance wood 1·01	23,400

The following table refers to wood pulled asunder in a direction perpendicular to that of the fibres:—

Kind of Wood.	Cohesion of a sq. in. perpendicular to fibres, in lbs.
Oak	2,316
Poplar	1,782
Larch	from 970 to 1,700
Memel fir	540 to 840
Scotch fir	562

84. Stiffness of Beams.—When a weight is laid upon the middle of a piece of timber which is supported only at the ends, it always bends more or less. When the weight bends the piece in a very small degree, the wood is said to be stiff; when the bending is considerable, it is called flexible. The stiffness of beams is proportional to the space they are bent through by a given weight, when the lengths are the same: but that two pieces of different lengths may be equally stiff, the

deflexion or bending should be proportional to their lengths. For a deflexion of one-fourth of an inch in a joist 20 feet long would not be attended with any bad effect; but if a joist 4 feet long were to bend one-fourth of an inch, it would be totally unfit for its purpose.

When a beam is supported at the ends only, in a horizontal position, and the weight rests upon the middle between the points of support, the law of deflexion is as follows:—Making $L =$ the length of bearing in feet, $W =$ the weight in pounds, $B =$ the breadth in inches, and $D =$ the depth in inches, $\frac{L^3 \times W}{B \times D^3}$ is as the deflexion.

But in order that a beam may be equally stiff, according to the definition of stiffness previously given (Art. 81), the deflexion should be inversely as the length; consequently, the weight that a beam will sustain, so that the deflexion shall be proportional to the length, is as the breadth and cube of the depth directly, and as the square of the length inversely; or $\frac{B \times D^3}{a \times L^2} = W$. That is, denoting the deflexion in inches by d, $\frac{L^3 \times W}{B \times D^3 \times d} =$ a constant number for the same material.

The quality of timber being the same, a beam will be stronger in proportion as its depth is greater; but there is a certain proportion between the depth and breadth, which, if it be exceeded, the beam will be liable to overturn, and break sideways. To avoid which, the breadth should never be less than that given by the following rule, unless the beam be held in its position by some other means: Divide the length in feet by the square root of the depth in inches, and the quotient multiplied by the decimal 0·6 will give the least breadth that should be given to the beam. When

the depth is not determined by other circumstances, the nearer its form approaches to that determined by the rule, the stronger it will be; and, from the same rule, another is easily obtained which will show the advantage of making beams thin and deep.

To find the strongest form for a beam, so as to use only a given quantity of timber, multiply the length in feet by the decimal 0·6, and divide the given area in inches by the product; and the square of the quotient will give the depth in inches.

The stiffest beam that can be cut out of a round tree is that of which the breadth is half the tree's diameter, or is to the depth as 1 is to the square root of 3, or as 1 is to 1·732, nearly; or as ·58 is to 1.

85. EXPERIMENTAL DATA.—Before these rules can be applied, the value of a must be obtained from experiments. It has been seen that the deflexion is as the weight and cube of the length directly, and as the breadth and cube of the depth inversely; and consequently, that the stiffness is as the latter directly, and as the former inversely; that is, the stiffness is as $\frac{B \times D^3}{L^3 \times W}$. Supposing, therefore, the deflexion d to have been obtained experimentally in any material, we should have $\frac{B \times D^3 \times d}{L^3 \times W}$ = a constant quantity, which being given, the deflexion in any other case might be found

The constant a is found as follows: the length is measured in feet, the other dimensions in inches; and the result is taken 40 times what the above formula gives, viz.,

$$\frac{40 \times B \times D^3 \times d}{L^3 W} = a.$$

And by this formula, the numbers or values of a, in the following tables, have been computed.

86. Experiments on the Stiffness of Oak.

Kind of Oak.	Spec. grav.	L in ft.	B in ins.	D in ins.	d in ins.	W in lbs.	Values of a.
Old ship timber	·872	2·5	1	1	0·5	127	·00998
Oak from young tree, King's Langley, Herts	·863	2	1	1	0·5	237	·0105
Oak from Beaulieu, Hants	·616	2·5	1	1	0·5	78	·0164
Ditto, another specimen	·736	2·5	1	1	0·5	65	·0197
Oak from old tree	·625	2	1	1	0·5	103	·024
Oak from Riga	·688	2	1	1	0·5	233	·0107
English oak	·960	7	2	2	1·275	200	·0119
Canadian oak	·867	7	2	2	1·07	225	·009
Dantzic oak	·787	7	2	2	1·26	200	·0105
Adriatic oak	·948	7	2	2	1·55	150	·0193
English oak	·748	2·5	1	1	0·5	137	·00934
Ditto, green	·763	2·5	1	1	0·5	96	·0133
Dantzic oak, seasoned	·755	2·5	1	1	0·5	148	·0087
Oak, sea oned	—	12·8	3·19	3·19	1·06 4·25	268 803	·008 ·0105
Oak, green	—	6·87	5·3	5·3	·433	7587	·005
Oak, green	—	23·58	5·3	5·3	2·7	706	·0095
Oak	—	8·52	5·08	6·22	0·709	4146	·0133
Oak (bois du brin)	—	16·86	10·66	11·73	0·67	4559	·0213
Oak (quercus sessiliflora	·807	2	1	1	0·35	149	·0117
Oak (quercus robur)	·879	2	1	1	0·35	167	·0104

87. Experiments on the Stiffness of Fir.

Kind of Fir.	Spec. grav.	L in ft.	B in ins.	D in ins.	d in ins.	W in lbs.	Values of a.
Riga yellow fir, medium	—	18	2	7	0·25	103	0·115
Yellow fir, from Long Sound, Norway	·6398	2	1	1	0·5	261	·00957
Yellow fir, Riga	·480 ·461	2·5 2·5	1 1	1 1	0·5 0·5	123 116	·0102 ·011
Ditto, Memel, medium	·553 ·544	2·5 2·5	1 1	1 1	0·5 0·5	143 145	·0089 ·0088
American* pine, supposed to be the Weymouth pine	·460 ·407	2 3	1 1	1 1	0·5 0·5	237 169	·0105 ·0112
White spruce, Christiana	·512	2	1	1	0·5	261	·00957
White spruce, Quebec	·4650	2	1	1	0·5	180	·0138
Pitch pine	·712	7	2	2	1·33	150	·0166
New England fir	·560	7	2	2	·970	150	·0121
Riga fir	·765	7	2	2	·912	150	·01137
Scotch fir, Mar Forest	·715	7	2	2	1·560	125	·0233
Larch, Blair, Scotland, dry	·622	2·5	1	1	0·5	93	·0137
Ditto, seasoned, medium	·644 ·554	2·5 2·5	1 1	1 1	0·5 0·5	101 112	·0126 ·0111
Ditto, very young wood	·396	2·5	1	1	0·5	45	·0284
Scotch fir	·529	2·5	1	1	0·5	89	·01437
Spruce fir, British	·555	2·5	1	1	0·5	103	·0124
Fir (bois du brin)	—	21·3	10·48	10·48	1·02	4389	·0115
Fir (bois du brin)	—	10·65	10·48	10·48	0·2245	4122	·022
Cowrie	·579	4	3	3	0·29	1680	·0088
Red pine	·544	4	3	3	0·36	1680	·0109
Yellow pine	·439	4	3	3	0·37	1680	·0112

* The reader will find an extensive table, containing the strength, &c., of various American woods, in vol. ii., Trans. Inst. Civ. Engineers, by Lieut. Dennison, R.E.

88. Experiments on the Stiffness of various Woods.

Kind of Wood.	Spec. grav.	L in ft.	B in ins.	D in ins.	d in ins.	W in lbs.	Values of a.
Ash from young tree, white coloured	·811	2·5	1	1	0·5	141	·009
Ash from old tree, red coloured	·753	2·5	1	1	0·5	118	·0113
Ash, medium quality	·690	2·5	1	1	0·5	78·5	·0163
Ash	·760	7	2	2	1·27	225	·0105
Beech	·688	7	2	2	1·025	150	·01277
Teak	·744	7	2	2	1·276	300	·0076
Poona (top)	·632	4	8	8	0·32	1680	·0097
Ditto (butt)	·658	4	8	8	0·25	1680	·0076
Elm	·540	7	2	2	1·42	125	·0212
	·544	2·5	1	1	0·5	99·5	·0128
Cedar of Lebanon	·486	2·5	1	1	0·5	86	·0355
Maple, common	·625	2·5	1	1	0·5	65	·0197
Abele	·511	2·5	1	1	0·5	84	·0152
Willow	·405	2·5	1	1	0·5	41	·031
Horse chestnut	·483	2·5	1	1	0·5	79	·0162
Lime tree	·483	2·5	1	1	0·5	84	·0152
Walnut, green	·920	2·5	1	1	0·5	62	·020
Spanish chestnut, green	·875	2·5	1	1	0·5	68·5	·0187
Acacia, ditto	·820	2·5	1	1	0·5	125	·0102
Plane, dry	·648	2·5	1	1	0·5	99·5	·0128
Alder, ditto	·555	2·5	1	1	0·5	80·5	·0159
Birch, ditto	·720	2·5	1	1	0·5	90·5	·0141
Beech, ditto	·690	2·5	1	1	0·5	97·5	·0131
Wych elm, green	·763	2·5	1	1	0·5	92	·014
Lombardy poplar, dry	·374	2·5	1	1	0·5	56·5	·0224
Honduras mahogany	·560	2·5	1	1	0·5	118	·0109
Spanish ditto	·853	2·5	1	1	0·5	93	·0137
Sycamore	·590	2·5	1	1	0·5	76	·0168
Pear tree, green	·792	2·5	1	1	0·5	59·5	·0215
Cherry tree, ditto	·690	2·5	1	1	0·5	92·5	·0138

89. Experiments on Oak from the Royal Forests.

Name of Forest.					Depression increased with time when loaded to this degree.		At the first fracture.		Values of a.	Values of c.
	Spec. grav.	L in ins.	B in ins.	D in ins.	W in lbs.	d in ins.	W in lbs.	l in ins.		
High Meadow Forest	·7926	22	·97	·96	80	0·25	400	2·9	·0175	826
Ditto	·7563	22	·95	·95	60	0·162	390	2·4	·0143	835
Parkhurst Forest (sawed)	·8770	22	·98	·95	90	0·235	370	2·6	·0188	770
Dean Forest	·747	22	·95	·95	70	0·18	840	1·15	·0137	780
Ditto	·799	22	·97	·97	80	0·155	410	1·45	·0112	820
New Forest (cleft)	·822	22	1·0	1·0	70	0·21	410	4·0	·0195	751
Ditto (sawed)	·723	22	1·0	1·0	80	0·112	415	1·35	·0091	760
Bere Forest (sawed)	·714	22	1·0	1·0	70	0·155	360	1·15	·0142	660
Ditto	·732	22	1·0	1·0	70	0·1	477	1·5	·0098	875
Ditto	·839	22	1·0	1·0	80	0·14	380	1·1	·0113	698
								Means	·0134	773

90. Formula for Stiffness.—It has been stated (85) that $\frac{40 \text{ B} \times \text{D}^3 \times d}{\text{L}^3 \text{ W}} = a$; therefore when d amounts to $\frac{1}{40}$th inch per foot, or $40 \times d = \text{L}$, the formula becomes $\frac{\text{B} \times \text{D}^3}{\text{L}^2 \text{ W}} = a$; and the following rules are constructed accordingly. When the deflexion is required to be less than is here assumed, then multiply the constant number a by some number that will reduce the deflexion to the proposed degree; for instance, if the deflexion should be only half of one-fortieth, multiply a by 2; if one-third of one-fortieth, multiply a by 3, &c. Also, if the deflexion may be greater than one-fortieth per foot, divide a by 2, 3, or any number of times that the proposed deflexion may exceed one-fortieth of an inch per foot.

91. Rules for the Stiffness of Beams.—To find the scantling of a piece of timber that will sustain a given weight at the middle, when supported at the ends in a horizontal position.

When the Breadth is given, multiply the square of the length in feet by the weight in pounds, and this product by the value of a opposite the kind of wood in the preceding tables; divide the product by the breadth in inches, and the cube root of the quotient will be the depth required in inches. Or $\text{D} = \sqrt[3]{\frac{\text{L}^2 \times \text{W} \times \text{tab. No.}}{b}}$

Example.—A beam of Norway fir is wanted for a 24-feet bearing to support 900 pounds, and the breadth to be 6 inches; required the depth? Here $\frac{24 \times 24 \times 900 \times \cdot 00957}{6} = 827$, and the cube root of 827 is 9·38, the depth required in inches.

When the Depth is given, multiply the square of the length in feet by the weight in pounds, and

multiply this product by the value of *a* opposite the name of the kind of wood in the preceding tables. Divide the last product by the cube of the depth in inches, and the quotient will be the breadth in inches required. Or $b = \frac{L^2 \times W \times \text{tab. No.}}{D^3}$

Example.—The space for a beam of oak does not allow it to be deeper than 12 inches; to find the breadth so that it may support a weight of 4,000 pounds, the bearing being 16 feet. Here $\frac{16 \times 16 \times 4000 \times \cdot 0164}{12 \times 12 \times 12} = 9\frac{3}{4}$ inches nearly, the breadth required.

The scantling of *inclined* beams will be found by the following rule:—

Multiply together the weight in pounds, the length of the beam in feet, the horizontal distance between the supports in feet, and the constant number *a* for the kind of wood; divide this product by 0·6, and the fourth root of the quotient will give the depth in inches. The breadth is assumed to be equal to the depth multiplied by the decimal 0·6.

Example.—Let the length of the beam be 20 feet, and the horizontal distance between the points of support 16 feet, and the weight to be supported one ton, or 2,240 pounds, by a beam of Riga fir. Then $\frac{2240 \times 20 \times 16 \times \cdot 011}{\cdot 6} = 13{,}141$; the fourth root of 13141 is $10\frac{3}{4}$ nearly, and $10\frac{3}{4} \times \cdot 6 = 6\frac{1}{2}$ nearly; therefore the beam should be $10\frac{3}{4}$ inches by $6\frac{1}{2}$ inches.

When the deflexion is caused by a weight that is uniformly distributed over a beam supported at both ends, it is shown by writers on the strength of materials that the deflexion produced by this weight uniformly distributed would be to the deflexion pro-

duced by the same weight collected in the middle of the length as 5 : 8, or as 0·625 : 1. Therefore, in the rules given above, it is only necessary to employ the weight in pounds multiplied by 0·625 instead of the whole weight, and the rest of the operation is the same as in those rules; therefore it will not be necessary to repeat them.

92. A BEAM FIXED AT ONE END and loaded at the other has the deflexion 16 times that produced by the same weight at the middle of the same beam when supported at the two ends; and if the load is uniformly distributed the deflexion is three-eighths of that produced when the load is all at one end.*

EXPERIMENTS ON THE STIFFNESS OF BEAMS SUPPORTED AT ONE END.

Kind of Wood.	Spec. grav.	L in ft.	B in ins.	D in ins.	Deflexion in ins.	Wt. producing deflexion in lbs.
Dantzic oak	·854	4	2	2	2·5	112
English oak	·922	4	2	2	1·176	112
Ditto, another specimen .	—	4	2	2	1·5	112
Riga fir	·537	4	2	2	1·34	112
Pitch pine	—	4	2	2	1·12	112
Beech	—	8	2	2	8·375	221
Riga fir	·605	2	8	8	1·02	1120
Red pine	·544	2	8	8	1·42	1120
American spruce . .	·504	2	8	8	1·32	1120
Adriatic fir	·467	2	8	8	1·00	1120
Cowrie	·626	2	8	8	·75	1120
Poona	·654	2	8	8	·62	1120

93. STRENGTH OF BEAMS TO RESIST CROSS STRAINS. —As it may sometimes be desirable to know the greatest weight a beam will bear without fracture, the following rules afford the means of obtaining it sufficiently near for practical purposes. The effect of deflexion is neglected, because it does not produce any material difference, unless the depth be very small and the length be considerable; a case which can rarely

* Barlow's "Strength of Timber."

happen in the construction of buildings: it is further of importance to remark, that one-fifth of the breaking weight causes the deflexion to increase with time, and finally produces a permanent set.

It is shown by writers on the strength of materials, that the strength of rectangular *beams supported at both ends* is directly as the breadth and square of the depth, and inversely as the length; therefore, $\frac{B \times D^2 \times c}{L} = W$, where c is a constant number to be ascertained by experiment. See pages 124, 125, 299, 300.

When a square beam is strained in the direction of its diagonal, its strength is less in the proportion of 0·7071 to 1.

The strength of a solid cylinder is as the cube of its diameter, therefore—

$$\frac{c \cdot D^3}{L \times 1{\cdot}7} = W.$$

A hollow cylinder is both stronger and stiffer than a solid one containing the same quantity of matter; therefore, when it is desirable to combine strength and lightness, cylinders may be made hollow. In timber this is rather too expensive an operation to be often employed, but there are cases where it is useful. The strength of a tube, or hollow cylinder, is to the strength of a solid one as the difference between the fourth powers of the exterior and interior diameters of the tube, divided by the exterior diameter, is to the cube of the diameter of a solid cylinder, the quantity of matter in each being the same.

The strongest beam that can be cut out of a round tree, is that of which the depth is to the breadth as the square root of 2 is to 1, or nearly as 7 is to 5. And the strength of a square beam cut from the same cylinder, or round tree, is to the strength of the

strongest beam nearly as 101 is to 110; but the square beam would contain more timber, nearly in the ratio of 5 to 4·714.

EXPERIMENTS ON THE STRENGTH AND STIFFNESS OF WOODS.

Kind of Wood.	Spec. grav.	L in ft.	B in ins.	D in ins.	Deflexion at the time of fracture in ins.	Wt. that broke the piece in lbs.	Values of the constant c.
Oak, English, young tree	·863	2	1	1	1·87	482	964
Ditto, old ship timber	·872	2·5	1	1	1·5	264	660
Ditto, from old tree	·625	2	1	1	1·38	218	436
Ditto, medium quality	·748	2·5	1	1	—	284	710
Ditto, green	·763	2·5	1	1	—	219	547
Ditto, from Riga	·688	2	1	1	1·25	357	714
Ditto, green	1·063	11·75	8·5	8·5	3·2	25812	595
Beech, medium quality	·690	2·5	1	1	—	271	677
Alder	·555	2·5	1	1	—	212	530
Plane tree	·648	2·5	1	1	—	243	607
Sycamore	·590	2·5	1	1	—	214	535
Chestnut, green	·875	2·5	1	1	—	180	450
Ash, from young tree	·811	2·5	1	1	2·5	324	810
Ditto, medium quality	·690	2·5	1	1	—	254	656
Ash	·753	2·5	1	1	3·38	314	785
Elm, common	·544	2·5	1	1	—	216	540
Ditto, wych, green	·763	2·5	1	1	—	192	480
Acacia, green	·820	2·5	1	1	—	249	622
Mahogany, Spanish seasoned	·853	2·5	1	1	—	170	425
Ditto, Honduras, seasoned	·560	2·5	1	1	—	255	637
Walnut, green	·920	2·5	1	1	—	195	487
Poplar, Lombardy	·374	2·5	1	1	—	131	327
Ditto, abele	·511	2·5	1	1	1·5	228	570
Teak	·744	7	2	2	4·00	820	717
Willow	·405	2·5	1	1	3	146	365
Birch	·720	2·5	1	1	—	207	517
Cedar of Libanus, dry	·486	2·5	1	1	2·75	165	412
Riga fir	·480	2·5	1	1	1·3	212	530
Memel fir	·553	2·5	1	1	1·15	218	545
Norway fir, from Long Sound	·639	2	1	1	1·125	396	792
Mar Forest fir	·715	7	2	2	5·5	360	315
Scotch fir, English growth	·529	2·5	1	1	1·75	233	582
Ditto, ditto	·460	2·5	1	1	—	157	392
Christiana white deal	·512	2	1	1	·937	343	686
American white spruce	·465	2	1	1	1·312	285	570
Spruce fir, British growth	·555	2·5	1	1	—	186	465
American pine, Weymouth	·460	2	1	1	1·125	329	658
Larch, choice specimen	·640	2·5	1	1	3	253	632
Ditto, medium quality	·622	2·5	1	1	—	223	557
Ditto, very young wood	·396	2·5	1	1	1·75	129	322
Riga fir	·610	4	3	3	—	4530	670
Red pine	·54	4	3	3	—	3780	560
Yellow pine	·439	4	3	3	—	2756	410
Cowrie	·579	4	3	3	—	4110	610
Poona	·632	4	3	3	—	3990	590

EXPERIMENTS MADE IN THE ROYAL ARSENAL, BY P. W. BARLOW.

No. of experiments.	Names of Woods.		Specific gravity.	Weight in lbs. which produced 1 in deflexion.	Breaking weight in lbs.	Value of c.
1	Acacia, English growth		710	—	1195	622
2	,, ditto		710	bore	1084	—
3	Oak, fast grown		903	660	999	520
4	,, slow grown		856	414	677	353
5	,, fast grown		972	550	999	520
6	,, slow grown		835	489	943	491
7	,, superior quality, 2 yrs. in store		748	896	1447	754
8	,, ditto, 16 ditto		756	680	1304	679
9	Tonquin bean	middle	1036	1388	2414	1283
10		outside	1080	1322	2228	1160
11	Locust	middle	972	1052	2116	1101
12		outside	936	940	2284	1189
13	Bullet tree	middle	1029	1860	1724	899
14		outside	1029	1832	1668	869
15	Greenheart	middle	1015	1332	1892	985
16		outside	986	1388	1612	854
17	Cabacally	middle	907	952	1668	869
18		outside	892	940	1556	810
19	African oak	middle	972	1168	1447	787
20		outside	972	1168	1657	863
21		middle	1015	1288	1643	856
22		outside	972	1097	1643	856
23	American black birch, very dry	middle	648	775	1279	656
24		outside	633	775	915	477
25		middle	648	644	1027	535
26		outside	669	831	1433	750
27	Common birch	middle	792	800	1164	607
28		outside	630	884	1304	679
29	Ash, dry	middle	727	660	1304	679
30		outside	702	660	1304	679
31	Elm, ditto	middle	554	436	772	402
32		outside	532	324	660	344
33	Christiana deal, ditto	middle	698	856	1052	548
34		outside	680	772	940	493
35	Memel deal, ditto	middle	590	786	1108	577
36		outside	590	856	1108	577

Note.—In these experiments the bearing distance was 50 inches, and the bars 2 inches square.

To find the weight that would break a rectangular beam when applied at the middle of its length, the beam being supported at the ends; multiply the breadth in inches by the square of the depth in inches; divide this product by the length in feet; then the quotient multiplied by the value of c in the table corre-

sponding to the kind of wood, will give the weight in pounds.

Example.—The length of a girder of Riga fir between the supports is 21 feet, its depth is 14 inches, and breadth 12 inches. Find the weight that would break it when applied in the middle. Opposite Riga fir in the table we find $c = 530$; and

$$\frac{12 \times 44 \times 14 \times 530}{21} = 59{,}360 \text{ pounds, or above 26 tons.}$$

If a beam of the same scantling and length had been supported at one end only, one-fourth of the weight would have broken it if applied at the unsupported end.

To find the weight that would break a solid cylinder when applied at the middle of its length, the cylinder being supported at the ends; find the value of c for the kind of wood in the table, and divide it by 1·7; multiply the quotient by the cube of the diameter in inches, and divide the product by the length in feet; the quotient will be the weight in pounds that would break the cylinder.

Example.—What weight would break a solid cylinder of ash, 12 feet long and 8 inches in diameter. For ash the value of c is 635 in the table, therefore

$$\frac{635 \times 8 \times 8 \times 8}{1{\cdot}7 \times 12} = 15{,}937 \text{ pounds.}$$

If the weight be uniformly diffused over the length of a beam, it will require to break it twice the weight that would break it when applied at the middle of its length.

When the beam is fixed at one end and loaded at the other, the breaking weight is one-fourth that where it is supported at each end and loaded in the middle, or the constant for beams supported at both ends must be divided by 4. And when the weight is uniformly diffused over the length, the beam will bear double

the weight that would break it when all applied at the end.

The strength of a beam fixed firmly at the ends is to that of one merely supported, in the ratio of 3 to 2.

94. Resistance to Detrusion.—There is another kind of cross strain which requires particular attention, as the strength of framing often depends upon it; that is, when a body is crushed across close to the points of support. Dr. Young has called the resistance to this kind of strain the "resistance to *detrusion.*" This resistance appears to be exactly proportional to the area of the section, and quite independent of its figure or position, and when the force is parallel to the fibres, the strength of fir to resist detrusion is from 556 to 634 pounds per square inch, or about one-twentieth of its cohesive power in the direction of the fibres. The resistance to being crushed across is, in all cases, equal, or very nearly equal, to the cohesive force of the body: and as in construction it is the lateral cohesion of timber that is usually exposed to a detruding force, we may conclude that the numbers already given will be sufficient, with those above stated, to assist the carpenter in proportioning the parts which have to support this strain.

95. Strength of Bent Timber.—In naval architecture it is always necessary to make use of a great quantity of bent timber. This, as far as can be done, is selected out of natural grown pieces, as nearly as possible of the required form, and is commonly known in the dockyards by the term *compass timber.* The great difficulty in obtaining compass timber led Mr. Hookey to extend a method which he had long practised for bending boat timbers, to the bending of the largest ship timbers, which was found to answer every possible expectation that could be formed of it; the

largest timbers, viz., pieces 18 inches square, being brought to any required curve in about fifteen minutes after being placed upon the machine.

The method of preparing the timber is as follows:— A fine saw-cut is made from one end, or both, according to the form into which the timber is to be bent; the length of it being also different, according to the length of the piece and the degree of curvature; but commonly, in a curve the height of which is about one-sixth or one-eighth of the whole length, the saw-cut from each end is about one-third of the length. The piece is then boiled for some hours, depending upon its lateral dimensions, and placed upon the machine, when the screws, &c., being applied, the required curvature is obtained, as above stated, in about twelve or fifteen minutes; after which it is screw-bolted, and is then ready for use.

The advantages attending this method of bending timber for the purposes of ship-building, are—1. That it dispenses with the use of compass timber, should it again become very scarce; and therefore no impediment would arise to the service if the necessary quantity of timber of this kind could not be in any way procured. 2. It saves a deal of the time and labour necessary for unstacking and restacking piles of timber, to procure pieces of requisite compass; any piece of the proper length and squarage being at once available with the application of the machine. 3. It saves a great quantity of timber, which is necessarily cut to waste in bringing compass timber to its required dimensions; the conversion, in some cases, taking away a considerable part of the original contents; while, in bending timber, the original and converted contents are nearly the same. From the experiments of Mr. Barlow, it appears that, taking the medium between the

natural grown pieces and those which are partly so and partly grain-cut, no defect in point of strength will be found on the side of those bent upon the above plan; and it also appears that, although there is an obvious falling off in the strength of pieces boiled for a long time, the defect is very small while the boiling or steaming is not continued beyond the proportion of an hour to an inch in thickness.*

96. RESISTANCE TO COMPRESSION.—When timber is subjected to a compressing force in the direction of its length, it will break either by bending, or by the crushing of the fibres, or by a combination of bending and crushing. This will depend upon the relation between the length and the diameter. If the length is less than eight times the diameter, it will break by crushing, expanding in the middle, and splitting into several pieces. If the length is more than eight times the diameter the force applied will cause it to bend before it crushes. The most reliable experiments are those made by Eaton Hodgkinson, and recorded in the "Philosophical Transactions" (1840), from which it appears that the strength of pillars having the length more than twenty-five times the diameter, and which only break by flexure, is directly as the fourth power of the diameter, and inversely as the square of the length; or $W = a \times \frac{d^4}{l^2}$, where W is the breaking weight in pounds, d the diameter in inches, l the length in feet, and a a constant, whose value is 24,500 for Dantzic oak, and 17,500 for red deal. The safe permanent load should not exceed one-tenth of the breaking weight. If the load does not act in the direction of the axis of the timber, the resistance is

* Barlow's "Strength of Materials.

much diminished, and is only one-third if the force acts down the diagonal instead of the axis.

For pillars less than twenty-five diameters in length the resistance to crushing must be taken into account. To find the strength in such cases first calculate the strength by the above formula and call it b, and let c be the crushing strength per square inch of the material as given in the table below. Then the true breaking weight is

$$W = \frac{b . c}{b + \frac{3}{4} c}.$$

The following table gives the resistance to crushing per square inch of section in pounds of various kinds of wood, the figures in the first column being for specimens moderately dry, and those in the second for specimens kept in a warm place two months longer than the others after being turned. Wet wood is found to be, as a rule, much weaker than dry :—

Kind of Wood.	Crushing strength per sq. in. in lbs.	
Alder	6831	6960
Ash	8683	9363
Baywood	7518	7518
Beech	7733	9363
Birch, English	3297	6402
Cedar	5674	5863
Deal, red	5748	6586
Ditto, white	6780	7293
Elm	—	10331
Fir, spruce	6500	6820
Hornbeam	4533	7290
Larch	3200	5568
Mahogany	8198	8198
Oak, Quebec	4230	5982
Ditto, English	6484	10058
Ditto, Dantzic	—	7730
Pine, pitch	6790	6790
Ditto, yellow	5375	5445
Ditto, red	5395	7518
Teak	—	12101
Walnut	6063	7227

CHAPTER III.

ON THE FRAMING OF TIMBERS.

Section I.—Floors.

97. Naked Flooring is the term applied in Carpentry to the timbers which support the flooring boards and ceiling of a room. There are different kinds of naked flooring, but they may be all comprised under the three following denominations, viz.:—single-joisted floors, double floors, and framed floors.

A *single-joisted* floor consists of only one series of joists. Plate I., Fig. 1,* shows a section across the joists of a single-joisted floor. Sometimes every third or fourth joist is made deeper, and the ceiling joists fixed to the deep joists, and crossing them at right angles. This is an improvement in a situation where there is not space for a double floor. Fig. 2 shows a section of a floor of this kind. It increases the depth of the floor very little, and will not allow sounds to pass so freely as a single-joisted floor, and the ceilings will stand better. The ceiling joists, *a*, *a*, are notched to the deep joists *b*, *b*, *b*, and nailed.

A *double floor* consists of three tiers of joists; that is, binding joists, bridging joists, and ceiling joists: the binding joists are the chief support of the floor,

* See Atlas of Plates.

and the bridging joists are notched upon the upper side of them; the ceiling joists are either notched to

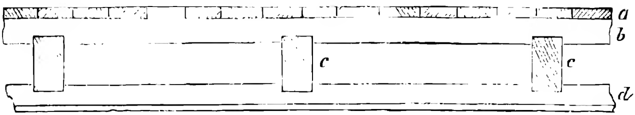


Fig. 17.

the under side, or framed between with chased mortises; the best method is to notch them. A section of such a floor is shown in Fig. 17, in which *a* is the flooring, *b* the bridging joists, *c* the binders, *d* the ceiling joists. Fig. 18 shows a transverse section of the same floor.

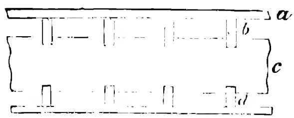


Fig. 18.

Framed floors differ from double floors only in having the binding joists framed into large pieces of timber, called girders. In Fig. 19 is shown a section of a

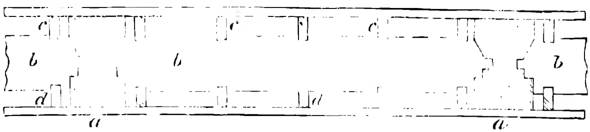


Fig. 19.

floor of this description, *a*, *a* being the girders, *b* the binders, *c* the bridging or floor joists, *d* the ceiling joists.

Single joisting makes a much stronger floor, with the same quantity of timber, than a double or framed floor, and may be constructed with equal ease to the same extent of bearing; but the ceilings are more subject to cracks and irregularities; consequently,

single-joisted floors of long bearings can be used only in inferior buildings.

When it is desirable to exhibit a perfectly plane ceiling of plaster, a double floor is used; and if the bearing is long, a framed floor becomes the most convenient.

98. SINGLE-JOISTED FLOORS.—In order to make a strong floor with a small quantity of timber, the joists should be thin and deep; but a certain degree of thickness is necessary, for the purpose of nailing the boards, and two inches is perhaps quite as thin as the joists ought to be made; though sometimes they are made thinner.

On account of flues, fire-places, and other causes, it often happens that the joists cannot have a bearing on the wall. In such cases a piece of timber, called a *trimmer*, is framed between two of the nearest joists that have a bearing on the wall. Into this trimmer the ends of the joists to be supported are mortised. This operation is called *trimming.*

The two joists which support the trimmer are called *trimming joists*, and they should be stronger than the common joists. In general it will be sufficient to add one-eighth of an inch to the thickness of a trimming joist for each joist supported by the trimmer. Thus, if the thickness of the common joists be 2 inches, and a trimmer supports four joists, then add four-eighths, or half an inch; that is, make the trimming joists each 2½ inches in thickness.

When the bearing exceeds 8 feet, single joisting should have herring-bone strutting, or slips of wood, nailed across each other diagonally between the joists to prevent them turning or twisting sideways, and also to stiffen the floor; when the bearing exceeds 12 feet, two rows of struts will be necessary, and so on, adding

another row of struts for each increase of four feet bearing; these struts should be in a continued line across the floor.

The relation between the breadth and depth of joists must depend upon the length, and the following table of scantlings is made on the supposition that the load on each joist is 100 pounds per lineal foot, the calculations being based on the formula previously explained (90 and 91); the scantlings are for fir joists:—

Length of joist in ft.	Depth, 4 ins.	Depth, 5 ins.	Depth, 6 ins.	Depth, 8 ins.	Depth, 10 ins.	Depth, 12 ins.
	Breadth in ins.	Breadth in ins.	Breadth in ins.	Breadth in ins.	Breadth in ins.	Breadth in ins.
6	$2\frac{1}{2}$	$1\frac{1}{2}$	—	—	—	—
8	5	$2\frac{1}{2}$	$1\frac{1}{3}$	—	—	—
10	—	—	3	$1\frac{1}{3}$	—	—
12	—	—	5	$2\frac{1}{2}$	$1\frac{1}{2}$	—
15	—	—	—	4	2	$1\frac{1}{2}$
20	—	—	—	—	5	3

For common purposes single joisting may be used to any extent that timber can be got deep enough for; but where it is desirable to have a perfect ceiling, the bearing should not exceed about 10 feet, on account of the partial strains produced by heavy furniture, such as bedsteads and the like, of which the greater part may rest upon only two or three of the joists, and of course bend these below the rest so as to break the ceiling. Also, where it is desirable to prevent the passage of sound, a framed floor is necessary. The passage of sound may be reduced in a single-joisted floor by putting rough boarding, nailed to slips, half way down the joists, and laying a coat of rough plaster called *pugging* thereon.

99. Framed Floors consist of girders, binding joists, bridging joists, and ceiling joists.

Girders are the chief supporters of a framed floor, being placed across the room from wall to wall; on these the binders are framed, the distance apart of the binders being about 6 feet, and that of the girders 10 feet. The weight of flooring sustained by the girders depends to some extent on the number of binders—thus in girders of 10 or 12 feet span there will be only one binder, consequently half the weight of the floor is borne directly by the walls, and half by the girder; in girders of 15 to 20 feet, having two binders resting on them, they will carry two-thirds the weight of the floor; and in those of 24 feet three-fourths of the weight; and so on. The load upon the girder will also increase with its length; if we take 100 pounds as the load per square foot, the weight on the floor will be 1,000 pounds for every foot length of girder. Hence it will be manifest that the fixed rule for calculating the scantlings of girders given by Tredgold must be incorrect. The scantlings given in the following table are calculated from the formula previously given (90 and 91), allowing a load of 100 pounds per square foot of flooring, and the deflexion not to exceed one-fortieth of an inch for every foot of length. A slight additional thickness is given to allow for framing the binders.

Length of girder in ft.	Depth, 10 ins.	Depth, 12 ins.	Depth, 15 ins.	Depth, 18 ins.
	Breadth in ins.	Breadth in ins.	Breadth in ins.	Breadth in ins.
10	6	4	$2\frac{1}{2}$	2
12	9	6	$3\frac{1}{2}$	3
15	14	8	5	$3\frac{1}{4}$
18	—	14	8	$4\frac{1}{2}$
21	—	—	13	8
24	—	—	$22\frac{1}{2}$	13
30	—	—	—	$22\frac{1}{2}$

When the breadth of a girder is considerable, it is often sawn down the middle and bolted together with the sawn sides outwards; the girders in the section, Fig. 4,* are supposed to be done in this manner. This is an excellent method, as it not only gives an opportunity of examining the centre of the tree, which in large trees is often in a state of decay, but also reduces the timber to a smaller scantling, by which means it dries sooner, and is less liable to rot. The slips put between the halves, or flitches, should be thick enough to allow the air to circulate freely between them.

When the bearing exceeds about 22 feet, it is very difficult to obtain timber large enough for girders; and it is usual in such cases to truss them. The methods in general adopted for that purpose have the appearance of much ingenuity; but, in reality, they are of very little use. If a girder be trussed with oak, all the strength that can possibly be gained by such a truss consists merely in the difference between the compressibility of oak and fir, which is very small indeed; and unless the truss be extremely well fitted at the abutments, it would be much stronger without trussing. All the apparent stiffness obtained by trussing a beam is procured by forcing the abutments, or, in other words, by cambering the beam. This forcing cripples and injures the natural elasticity of the timber: and the continual spring, from the motion of the floor, upon parts already crippled, it may easily be conceived, will soon so far destroy them as to render the truss a useless burden upon the beam. This is a fact that has been long known to many of our best carpenters, and which has caused them to seek for a remedy in iron trusses; but this method is quite as bad as the former, unless there be an iron tie as an abutment to the truss; for

* See Atlas.

the failure of a truss is occasioned by the enormous compression applied upon a small surface of timber at the abutments. The defects of ordinary trussed girders are very apparent in old ones, as it is not simply strength that is required, but the power of resisting the unceasing concussions of a straining force capable of producing a permanent derangement in a small surface at every impression.

The principle of constructing girders of any depth is the same as that of building beams, and when properly conducted is as strong as any truss can be made of the same depth. The most simple method consists in bolting two pieces together, with keys between, to prevent the parts sliding upon each other; the upper one of hard compact wood, the lower of tough straight-grained. The joints should be at or near the middle of the depth. Fig. 5, Plate I.,* shows a beam put together in this manner. The thickness of all the keys added together should be somewhat greater than one-third more than the whole depth of the girder; and if they be made of hard wood, the breadth should be about twice the thickness.

Fig. 6 is another girder of the same construction, excepting that it is held together by hoops instead of bolts. The girder being cut so as to be smaller towards the ends, would admit of these hoops being driven on till they would be perfectly tight, and would make a very firm and simple connection.

In Fig. 7 the parts are tabled or indented together, instead of being keyed, and a king-bolt is added to tighten the joints; the upper part of the girder being in two pieces. The depth of all the indents added together should not be less than two-thirds of the whole depth of the girder.

* See Atlas.

Another method of constructing a girder consists in bending a piece into a curve, and securing it from springing back by bolts or straps. A girder constructed in this manner is shown by Fig. 8. The pieces should be well bolted, or strapped, and keys or tables inserted to prevent any sliding of the parts. In this manner a beam might be built of any depth that is necessary in the erection of buildings, and, by breaking the joints, of any length that is likely to be needed in the construction of floors.

The following rule may be used for finding the proper scantling or dimensions of these girders, viz. :—Multiply $1\frac{1}{2}$ times the area of floor the girder supports in feet, by the length of bearing in feet; divide this product by the square of the depth in inches, and the quotient will be the breadth of the girder in inches.

The thickness of the bent pieces may be about one-fiftieth part of the bearing, and as many of them should be added as will increase the depth to that proposed, unless the whole depth of the curved pieces exceeds half the depth of the girder; and in that case straight pieces should be added to the under side, so as to make the whole depth of the straight parts exceed the depth of the curved parts. When pieces cannot be got sufficiently long for the girder, care should be taken to have no joints near the middle of the length in the lower half of the girder.

Fig. 8 shows a girder for a 40-feet bearing with the lower half scarfed at *a*, with a plain butting joint in the curved part at *b*.

As the strain is always greatest at the middle of the length of a girder, it would be well to avoid making mortises there, if possible, either for binding joists or for any other purpose; and the most straight-grained part of the beam should be put to the under side.

Also, timber girders should not be built into the wall, but an open space should be left round their ends, either by laying a flat stone over them, or by turning an arch to carry the wall above.

Girders should be laid from 9 to 12 inches into the wall, according to the bearing.

100. BINDING JOISTS are framed into the girders as shown by Fig. 9 (Atlas, Plate I.). Great care should be taken that both the bearing parts *a*, and *b*, fit to the corresponding parts of the mortise. This is the most important part to be attended to; the tenon should be one-sixth of the depth, and at one-third of the depth from the lower side. The scantlings will depend upon the bearing and distance apart. In the following table the binders are supposed 6 feet apart, and the weight of floor 100 pounds per square foot; the timber being fir:—

Length of binder in ft.	Depth, 6 ins.	Depth, 8 ins.	Depth, 10 ins.	Depth, 12 ins.	Depth, 15 ins.
	Breadth in ins.	Breadth in ins.	Breadth in ins.	Breadth in ins.	Breadth in ins.
5	3	2	—	—	—
7	5	3½	2½	2	—
9	—	6	3½	2½	—
12	—	13	7½	4½	3
15	—	—	13	8	4½
20	—	—	—	17½	9½

BRIDGING JOISTS will have the same scantlings as those for single-jointed floors (98), allowance being made for the notching on the binders.

101. CEILING JOISTS which have no load to carry but that of the lath and plaster need not be more than 1½ to 2 inches thick; the scantlings for fir joists in the table below are the smallest that should be given to ceiling joists, and are calculated on the supposition that the weight of the ceiling is about 12 pounds on

every lineal foot of each joist, which should never be more than 11 inches apart, nor have more than 15 feet bearing:—

Length of ceiling joist.	Depth, 3 ins.	Depth, 4 ins.	Depth, 5 ins.	Depth, 6 ins.
Ft.	Breadth in ins.	Breadth in ins.	Breadth in ins.	Breadth in ins.
8	2	1½	—	—
10	3	2	1½	—
12	—	2½	2	1½
15	—	3½	2½	2

102. General Remarks Respecting Floors.—Girders should never be laid over openings, such as doors or windows, if it be possible to avoid it; and when it is absolutely necessary to lay them so, the wall-plates, or templets, must be made strong, and long enough to throw the weight upon the piers. It is, however, a bad practice to lay girders obliquely across the rooms; it is much better to put a strong piece as a wall-plate.

Wall-plates and templets should be made stronger as the span becomes longer: the following proportions may serve for brick walls:—

				Ins.		Ins.
For a	20-feet bearing,	wall-plates		4½	by	3
„	30	„	„	5½		4
„	40	„	„	6½		5

Floors should always be kept about three-fourths of an inch higher in the middle than at the sides of a room when first framed; and also the ceiling joists should be fixed about three-fourths of an inch in 20 feet higher in the middle than at the sides of the room; as all floors, however well constructed, will settle in some degree.

In laying the flooring, the boards should always be

made to rise a little under the doorways, in order that the doors may shut close without dragging; and at the same time it assists in making them clear the carpet.

102*a*. RULES FOR SCANTLINGS OF FLOOR TIMBERS.—The following formulæ and rules for finding the scantlings of the timbers used in flooring are taken from the sixth edition of *Tredgold's Carpentry*, the floor being supposed to have to sustain a distributed load of 120 lbs. on every superficial foot, and the timber to be Riga fir.

For *single-joisted* floors in which the *joists* are laid 12 inches from middle to middle, let L be the length of bearing of the joists in feet, B the breadth, and D the depth in inches; then if any two of the dimensions are given, the third can be calculated from the equation

$$D^3 = \frac{3\,L^3}{4\,B}, \text{ or } D = L\left(\frac{3}{4\,B}\right)^{\frac{1}{3}}$$

Supposing the length and breadth to be given, then the depth is found by the following

RULE.—Divide 3 by 4 times the breadth in inches, and multiply the cube-root of the quotient by the length in feet. Then the product is the required depth in inches.

The same rule will apply to bridging-joists for double floors.

Ceiling-joists which have only to carry a load of 12 lbs. on each superficial foot, may have their scantlings determined by the formula,

$$D = \frac{L}{2}\left(\frac{3}{5\,B}\right)^{\frac{1}{3}}$$

RULE.—To determine the depth in inches of a ceiling-joist, whose length and breadth are given, divide 3 by 5 times the breadth in inches, and multiply the

cube-root of the quotient by half the length of bearing in feet.

It is better to notch ceiling-joists to the under side of the binding-joists, and nail them, than to mortise and chase them in, because it requires less labour, does not weaken the binding-joists, and the ceiling stands better. Oak is not so good a material for ceiling-joists as fir, because it is more subject to warp, particularly if it be not well seasoned.

The scantlings of *Binding-joists* placed 6 feet apart from middle to middle, and carrying both ceiling and bridging-joists, are determined by the formula,

$$D = L\left(\frac{9}{2\,B}\right)^{\frac{1}{3}}$$

from whence we obtain the following

RULE.—To find the depth in inches of a binder whose length of bearing and breadth are given, divide 9 by twice the breadth in inches and multiply the cube-root of the quotient by the length in feet. Or, if the breadth is required when the depth is given, divide 9 times the cube of the length by twice the cube of the depth.

Binding-joists that have only to carry a ceiling may have their scantlings found by the same rule as that given above, only the load may be taken at 12 lbs. per square foot, instead of 120 or

$$D = L\left(\frac{9}{20\,B}\right)^{\frac{1}{3}};$$

the divisor in the above rule being 20 times the breadth instead of twice. This will suffice for ordinary ceilings, but where there is a large amount of ornamentation or panelling, the scantling must be made proportionally greater.

Girders placed 10 feet apart from middle to middle

and supporting the binders, must have their scantlings regulated, to a certain extent, by the number and position of the binders. If there is one binder only at the middle, or if there are three, five, or a greater number of binders at equal distances apart, the formula for the scantling is,

$$B = \frac{6\ L^3}{D^3}$$

RULE.—To find the breadth of the girder in inches, divide 6 times the cube of the length in feet by the cube of the depth in inches. Or, to find the depth, divide 6 by the breadth, and multiply the cube-root of the quotient by the length.

When there are two binders resting on the girder, the formula is,

$$B = \frac{16\ L^3}{3\ D^3}$$

RULE.—Sixteen times the cube of the length in feet divided by 3 times the cube of the depth in inches, gives the breadth in inches. Or, to find the depth, divide 16 by 3 times the breadth, and multiply the cube-root of the quotient by the length.

When there are four binders resting on the girder the formula is,

$$B = \frac{29\ L^3}{5\ D^3}$$

RULE.—Twenty-nine times the cube of the length in feet divided by 5 times the cube of the depth in inches, gives the breadth in inches. Or, to find the depth, divide 29 by 5 times the breadth, and multiply the cube-root of the quotient by the length.

The rules given above are for ordinary house-floors. In the case of a warehouse the strength of the timbers should be made at least 3 times as great, which can be

done either by making the breadth 3 times as great, or by multiplying the depth as given by the foregoing formulæ, by 1·44 or nearly $1\frac{1}{2}$.

Section II.—Roofs.

103. The Object of a Roof is to cover and protect a building from the effects of the weather, and also to bind and give strength and firmness to the fabric. To effect these purposes it should neither be too heavy nor too light, but of a just proportion in all its parts to the magnitude of the building.

In carpentry, the term *Roof* is applied to the framing of timber which supports the covering of a building. The *Pitch* of a roof, or the angle which its inclined side forms with the horizon, is varied according to the climate and the nature of the covering. The inhabitants of cold countries make their roofs very high, while those of warm countries, where it seldom rains or snows, make their roofs nearly flat. But even in the same climate the pitch of the roof has been subject to many variations. Formerly roofs were made very high, to prevent snow drifting between the slates, and perhaps with the notion that the snow would slide off easier: but where there are parapets, a high roof is attended with bad effects, as the snow slips down and stops the gutters, and an overflow of water is the consequence: besides, the water in heavy rains descends with such velocity that the pipes cannot convey it away soon enough to prevent the gutters being overflown; and the drift of snow is prevented by the greater care taken to render the joints close, and by boarding under the slates instead of using laths. In high roofs the action of the wind is one of the most considerable forces they have to sustain, and it appears to have been with

a view of lessening their height that the Mansard or curb roof was invented (Fig. 27, page 148).

The height of a roof at the present time is rarely above one-third of the span or distance between the walls which support it, and it should never be less than one-sixth. The most usual pitch for slates is when the height is one-fourth of the span, or when the angle with the horizon is 26½ degrees.

The kinds of covering used for timber roofs are copper, lead, galvanized iron, zinc, slates of different kinds, tiles, shingles, reeds, straw, and heath. Taking the angle for slates to be 26½ degrees, the following table will show the degree of inclination that may be given for other materials:—

Kind of Covering.	Inclination to the horizon. Deg.	Min.	Height of roof in parts of span.	Wt. upon a sq. ft. of roofing.
Copper, lead, or zinc	3	50	1/30	copper 1·00 lbs. lead 7·00
Slates, large	22	0	1/5	11·20
Ditto, ordinary	26	33	1/4	from 9·00 to 5·00
Stone slate	29	41	2/7	23·80
Plain tiles	29	41	2/7	17·80
Pantiles	24	0	2/9	6·50
Thatch of straw, reeds, or heath	45	0	1/2	straw 6·50
Force of wind does not generally exceed	—		—	40·00

The simplest kind of roof is that called a *lean-to* or *shed-roof*, in which a number of timbers called *rafters* rest upon wall plates laid on two walls, one of which is higher than the other, as shown in Fig. 20, and consequently the rafters have a slope or *fall* towards the lower wall.

A very common form of roof in town houses built in rows is the *V-roof*, or double lean-to, as shown in Fig. 21.

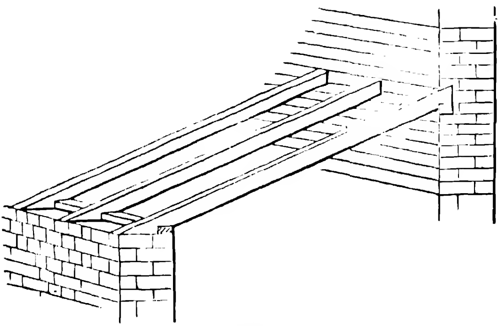


Fig. 20.

In this roof the rafters (R) rest at their feet upon two bearers (B) carried from back to front of the house,

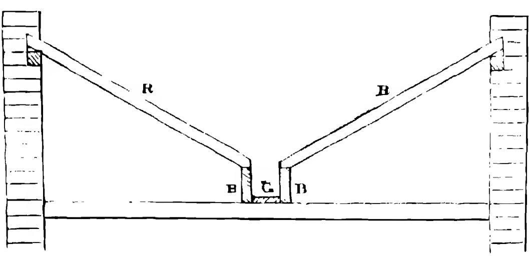


Fig. 21.

and forming a trough-gutter (G) along the middle. The upper ends of the rafters are supported by the party-walls.

When the walls are both of one height the rafters are generally put together in pairs, sloping upwards from each wall to a *ridge-piece* (marked R) in the centre, as shown in Fig. 22. The feet are spiked to the ends

of the ceiling joists (T), which act as ties to prevent the rafters from spreading outwards.

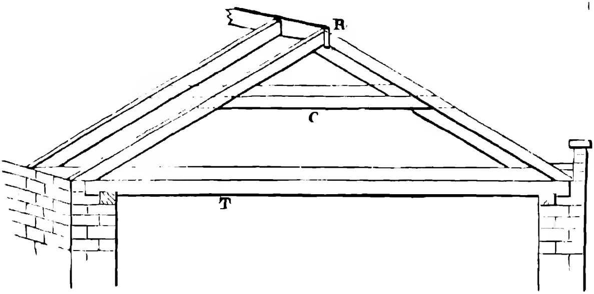


Fig. 22.

A *Hip-roof* is one whose ends rise immediately from the wall, having the same inclination to the horizon as the sides have; a hipped-roof is of a pyramidal form, and the angles made by the meeting of the planes which form the pyramid are called the *hips*, the timbers which follow the line of the hips being called *hip-rafters*. *Jack-rafters* are the short rafters rising from the walls and framing into the hip-rafters. The length of the hip-rafter is found by dropping a plumb-line from its vertex to meet a horizontal line from its foot, then adding together the squares of the lengths of those two lines, and taking the square-root of their sum.

The wall plate on which the feet of the rafters rest is laid all round the wall in a hip-roof, and is braced at the angles by a *diagonal-tie* cocked down on each plate; framed at right angles into this is a short piece, called a *dragon-tie*, which bisects the angle made by the wall plates, and on which the heel of the hip-rafter rests.

A *Valley* is the opposite of a hip, being the internal angle formed by the two planes of a roof. *Valley-boards* are boards laid on each side of the angle to receive the lead, and are feather-edged.

Gutters are channels formed between the inclined side of a roof and the adjoining parapet wall (C. Plate II.), or between the two inclined sides of a double roof (D. Plate II.). They are formed of longitudinal planks laid upon transverse bearers nailed to the feet of the rafters, having steps or drips of 2 or 3 inches every 10 or 12 feet length; they are laid with a fall from end to end, and consequently are wider at the upper than the lower end, except in parallel or trough gutters (Fig. 21, page 143); feather-edged boarding is laid up the sides of the gutter on the feet of the rafters, about 9 inches wide, to receive the lead lining, which turns up under the slating.

In order to prevent the rafters of a roof from thrusting out at the feet, a horizontal piece of timber called a *collar* (marked C, Fig. 22) is nailed across each pair of rafters, at any convenient height, and *halved* on to them, as shown on Fig. 23. When this piece is placed at the *feet* of the rafters it is called a *tie-beam* (marked T), and in that case the roof has no outward thrust on the wall. When the span of the roof is above 20 feet, the tie-beam will have a tendency to bend in the middle; to obviate which a piece of timber called a *king-post* (marked K, Fig. 24)* is introduced between the heads of the rafters and the centre of the tie-beam; into the head of this post the rafters are framed, and thus hold up the post, *shoulders* being formed in it for that purpose, the king-post holding up the centre of the tie-beam by means of a strap which is passed under it. Such a combination of timbers is called a *truss* or

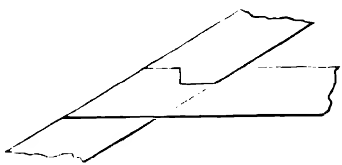


Fig. 23

* See also Atlas, Plate II.

principal, and is suitable for a roof of 20 to 30 feet span. When two upright pieces (Fig. 25) are introduced to hold up the tie-beam, they are called *queen-posts*

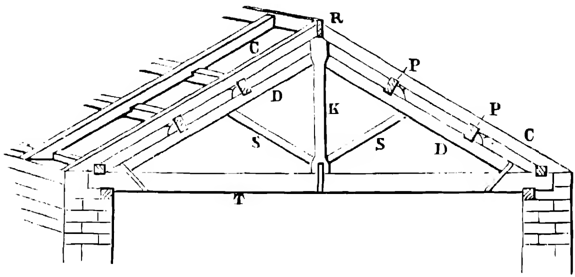


Fig. 24.

(marked Q), and the horizontal piece between their heads is called the *straining-beam* (marked B); by this

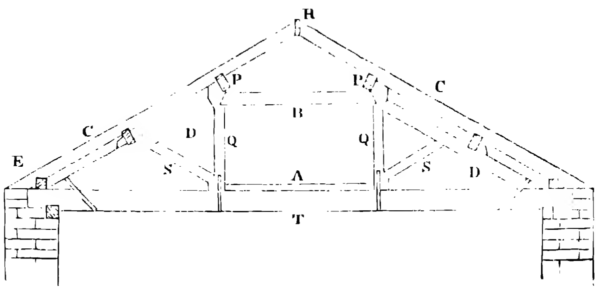


Fig. 25.

beam the reactions of the heads of the rafters (D) are made to balance each other.

In order to stiffen the main rafters, pieces of wood called *struts* (marked S) are framed into the feet of the king or queen-posts and also into the centre of the

rafters. In the king-post roof the opposite thrusts of the struts counterbalance each other on the foot of the king-post; but in the queen-post roof their thrusts have to be conveyed along a *straining sill* (A) placed between the feet of the queen-posts upon the top of the tie-beam. This kind of truss is suitable for roofs over 30 feet span. When the span exceeds 45 feet, a truss, of the form shown in Plate III.,* Fig. 1, will best answer the purpose. The mode of framing the feet of the rafters into the tie-beam is shown in Fig. 26.

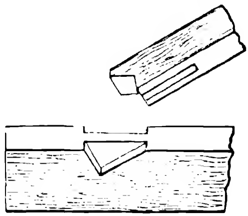


Fig. 26.

When a roof is framed in either of the foregoing methods, the trusses do not themselves directly carry the slates or other covering, but are placed about 10 feet apart, and receive longitudinal beams, called *purlins* (marked P), notched down upon the *principal rafters* (D) of each truss, about 5 feet apart; upon these purlins are notched the *common rafters* (marked C), about 11 inches apart, on which the boarding or battening to receive the covering of slates, &c., is nailed. The feet of the common rafters are spiked upon a piece of timber laid upon the wall or upon the ends of the tie-beam, which is called the *pole-plate* (marked E).

When the covering for the roof is to be lead or zinc, the rafters must be laid over with close-boarding, on which the metal is secured by means of rolls of wood placed every 2 feet or 3 feet apart, and fixed from bottom to top, and over which the metal is dressed. If slate or tile is the material of the covering, battens or laths are nailed horizontally along the rafters, at distances

* See Atlas.

apart regulated by the gauge of the slates or tiles. At the eaves of a slated roof, an *eaves-board* is generally laid, to give solidity to the slating at that part; and in order to check the rush of water into the gutter at the eaves, the slates are tilted up there by means of a strip of wood called a *tilting-fillet;* similar fillets are also laid along the edges of valleys, and wherever the slating abuts against a wall.

When the ridge or hips are to be covered with lead or zinc, a rounded roll of wood is spiked to the whole length of hip-rafter or ridge piece, and is called a *ridge-roll.* When there is a parapet wall at the eaves of the roof, a gutter has to be formed by means of horizontal pieces called *bearers,* spiked to the feet of the rafters, and on which the *gutter-boards* are laid to receive the lead.

A CURB-ROOF, or MANSARDE, is one in which the rafters on each side are in two separate lengths, and

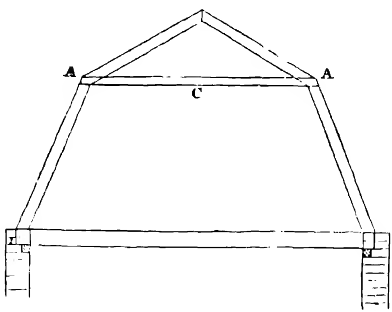


Fig. 27.

form an external angle (A) at their junction, as in Fig. 27. A collar-beam (C) is introduced at the junction of the two sets of rafters. The feet of the lower rafters are secured to the ends of the ceiling-joists of the floor

below. The object of this form of roof is to obtain space for rooms, of which the collars (C) forms the ceiling joists.

Roofs may have the feet of their rafters prevented from thrusting outwards without employing a *horizontal* tie-beam, as shown in Figs. 28, 29, 30.

Fig. 28.

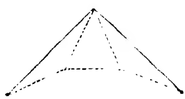


Fig. 29.

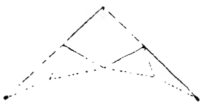


Fig. 30

104. Domical or Cylindrical roofs may be constructed of timber, on the principle suggested by Philibert de Lorme, as shown in Fig. 31. In this

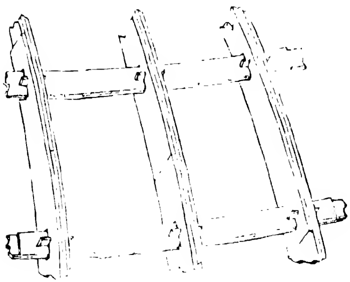


Fig. 31.

method a series of curved ribs are placed so that their lower ends stand upon a curb at the base, and the upper ends meet at the top, diagonal struts being introduced between them. These ribs are formed of planks put together in thicknesses, with the joints crossed, and well bolted together; there should be at least three thick-

nesses in each rib, not bent, but applied flat together in a vertical plane, and their edges cut to the proper curvature; the layers of the ribs may be held together without bolts, by merely the horizontal rings or purlins, which pass through a mortise hole in the middle and have themselves a slit into which a wooden key is driven on each side of the rib, as shown in the figure. Examples of this form of roof can be seen in the Town Hall and Corn Exchange at Farnham, Surrey, built by

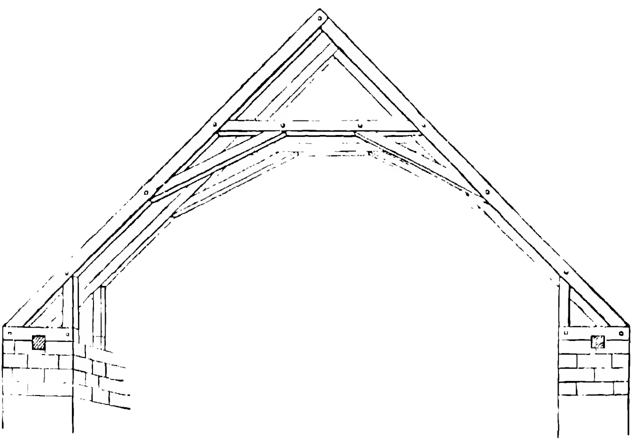


Fig. 32.

Mr. Tarn. Sometimes the main ribs are formed of planks bent to the sweep, and bolted one on the other, as in the roof of the Great Northern Station, King's Cross, which has a span of 105 feet; part of this roof, however, has been replaced by iron ribs

105. COLLAR-ROOFS are frequently used over Gothic buildings of moderate span, as shown in Fig. 32. In this form of roof the *collar* is placed high up, tenoned into the rafters, and secured thereto with oak pins.

Diagonal pieces, called *braces*, are also tenoned into both the collar and the rafters, and secured with pins. The foot of each rafter is framed into a horizontal *wall-piece*, which lies across the whole thickness of the wall, and is notched down on the wall-plate; into the inner end of this wall-piece a vertical strut is framed, and also into the rafter itself. By this arrangement the

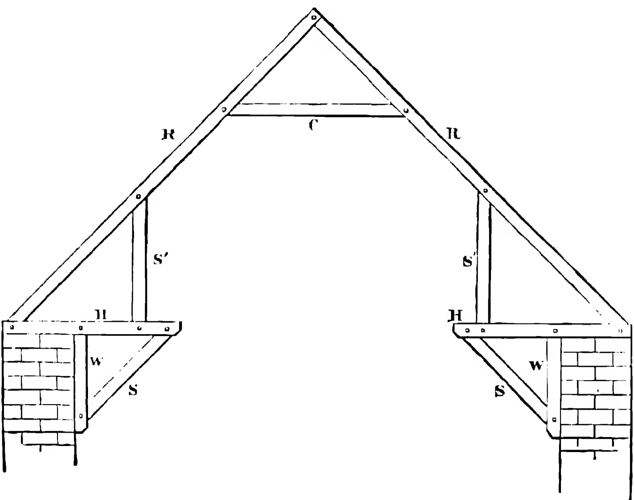


Fig. 33.

outward thrust on the wall is greatly counteracted, and the weight thrown nearly vertically upon it.

HAMMER-BEAM roofs are sometimes found over old Gothic buildings, and their form is shown in Fig. 33.

In this kind of roof we may suppose that the feet of the rafters are first prevented from spreading by being framed into a tie-beam; the middle part of the

tie-beam is afterwards cut away, and the remaining parts (marked H) are called *hammer-beams.* To prevent these beams from thrusting outwards, a diagonal strut (marked S) is framed into its inner end, and also into a vertical wall-piece (W), which is itself framed

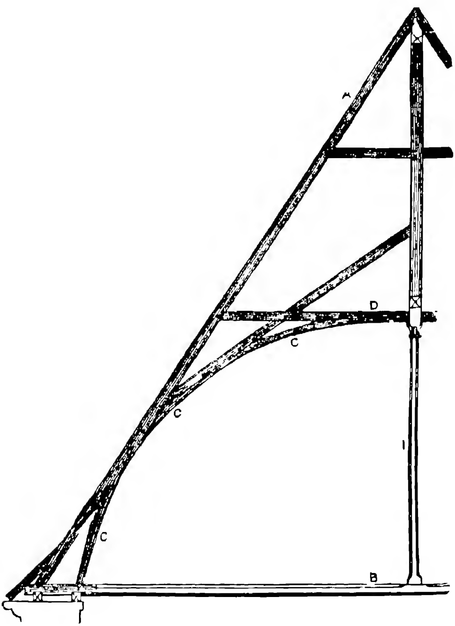


Fig. 34.

into the under side of the hammer-beam. A vertical strut (marked S′) is also placed between the rafter and the end of the hammer-beam. By this means a considerable amount of the thrust of the rafters is thrown vertically down the walls. There will, however, always remain sufficient horizontal thrust to push out the

walls, if they are not built very strong, or supported by external buttresses.

One of the lightest and best combined specimens of timber framing for an open roof is in the chief apartment of the episcopal palace of Auxerre, which is now changed into the Prefecture for the department. In the engraving on page 155 (Fig. 34) will be remarked between the tie-beam B and the stay D, a series of curves CCC intended to receive oak planking or shingles, to form a circular vaulting slightly depressed in the centre. The king-post I passes down the centre of the half section of a circle, as it were, and suspends the tie-beam. The purlins, rafters, and main couples are tied together, and the former to the ridge-tree by cross pieces. The planking is nailed to the circles and the joints hidden by mouldings, which also serve to give strength and stability to the framing. The whole of the wood-work is as light as it is solid, and no particle of material has been allowed to remain that was not necessary. Several examples remain of a modification of this system, but with interior vaulting preserved. In some cases, the use of the tie-beam is dispensed with, and the rafters in each pair tied together by cross pieces as described above. In others, where the tie-beam is retained, the top stay is deflected from the horizontal, and made to form a portion of the circle to support the planking of the vaulting.

The most remarkable specimen of hammer beam roof, as well as the largest and most magnificent, is that of Westminster Hall (Fig. 35).

The angle of the roof is formed in what workmen still term common pitch, the length of the rafters being about three-fourths of the entire span. The cutting off the girders, or tie-beams, which, crossing from wall to

wall in common roofs, restrain all lateral expansion, was the first circumstance peculiar to this construction. To provide against lateral pressure, we find trusses, or principals, as they are technically called, raised at the distances of about eighteen feet throughout the whole

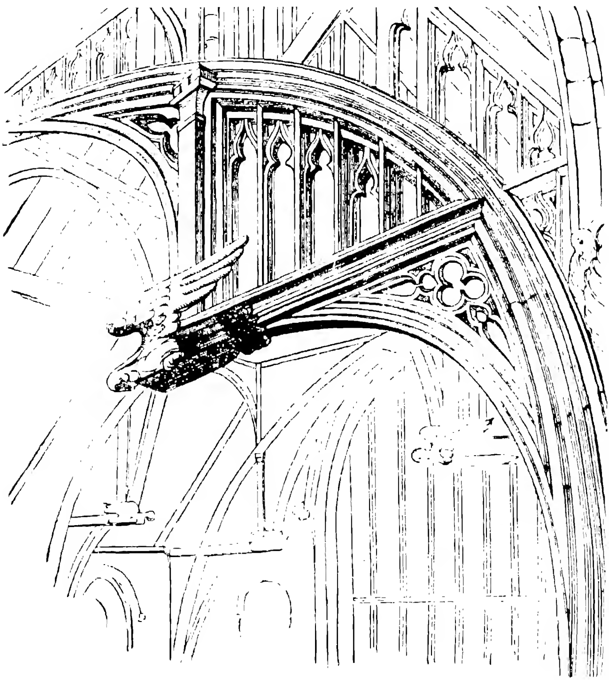


Fig. 35

length of the building. The trusses abut against the solid parts of the walls between the windows, which are strengthened in those parts by arch buttresses on the outside. Every truss comprehends one large arch, springing from corbels of stone, which project from

the walls at twenty-one feet below the base line of the roof, and at nearly the same height from the floor. The ribs forming this arch are framed at its crown into a beam which connects the rafters in the middle of their length. A small arch is turned within this large one, springing from the base line of the roof, and supported by two brackets or half arches issuing from the springers of the main arch. By this construction of the trusses, each one acts like an arch; and by placing their springers so far below the top of the walls, a more firm abutment is obtained; subordinate timbers co-operate to transfer the weight and pressure of intermediate parts upon the principals; and thus the whole structure reposes in perfect security, after more than four centuries from its first erection.*

106. EXAMPLES OF TIE-BEAM ROOFS OF LARGE SPAN.—Fig. 36 is the roof of the chapel of the Royal Hospital at Greenwich, constructed by Mr. S. Wyatt.

The trusses are seven feet apart, and the whole is covered with lead, the boarding being supported by horizontal ledgers, *h*, *h*, of six by four inches.

This is a beautiful roof, and contains less timber than most others of the same dimensions. The parts are all disposed with great judgment. Perhaps the iron rod is unnecessary; but it adds great stiffness to the whole.

The iron straps at the rafter feet would have had

* The principle of the construction of these kinds of roofs is founded on that property of the triangle, that whilst the lengths of the sides remain the same, the angles are unchangeable; and, in this case, all the pieces (of timber) are arranged to form the sides of triangles, and thus all the joints are rendered fixed and immovable. Thus what would at first sight have the appearance of being a weight upon the roof, is, in fact, its strength and safety. Our ancestors did not attempt to conceal these roofs with a ceiling; but justly proud of their ingenuity in construction, exposed the whole to view, carved and ornamented on all the more prominent parts.

more effect if not so oblique. Those at the head of the post are very effective.

We may observe, however, that the joints between

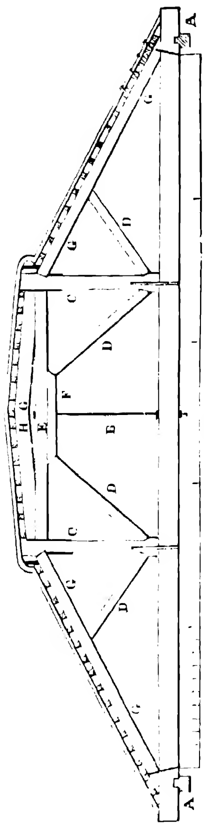


Fig. 36.

		Inch. scantling.
AA,	is the tie-beam, 57 feet long, spanning 51 feet clear	14 × 12
CC,	Queen-posts	9 × 12
D,	Braces	9 × 7
E,	Truss beam	10 × 7
F,	Straining piece	6 × 7
G,	Principal rafters	10 × 7
H,	A cambered beam for the platform	9 × 7
B,	An iron string, supporting the tie-beam	2 × 2

the straining beam and its braces are not of the best kind, and tend to bruise both the straining beam and the truss beam above it.

Fig. 37 is the roof of St. Paul's, Covent Garden, constructed by Mr. Wapshot in 1796.

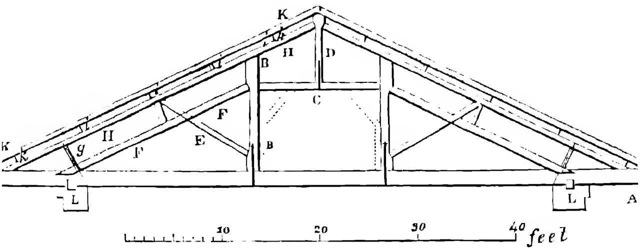


Fig. 37.

		Inch. scantling.
AA,	Tie-beam, spanning 50 feet 2 inches	16 × 12
B,	Queen-post	9 × 8
C,	Truss-beam	10 × 8
D,	King-post (14 at the joggle)	9 × 8
E,	Brace	8 × 7½
FF,	Principal brace (at bottom)	10 × 8½
HH,	Principal rafter (at bottom)	10 × 8½
g g,	Studs supporting the rafter	8 × 3

This roof far excels the original one put up by Inigo Jones. One of its trusses contains 198 feet of timber. One of the old roof had 273, but had many inactive timbers, and others ill-disposed. The internal truss FCF is admirably contrived for supporting the exterior rafters, without any pressure on the far projecting ends of the tie-beam. The former roof had bent them greatly, so as to appear ungraceful.

We think that the camber (six inches) of the tie-beam is rather hurtful; because, by settling, the beam lengthens; and this must be accompanied by a *considerable* sinking of the roof. This will appear by calculation.

Fig. 38 is the roof of the Birmingham Theatre, constructed by Mr. George Saunders. The span is 80 feet clear, and the trusses are 10 feet apart.*

* See also Atlas, Plate II.

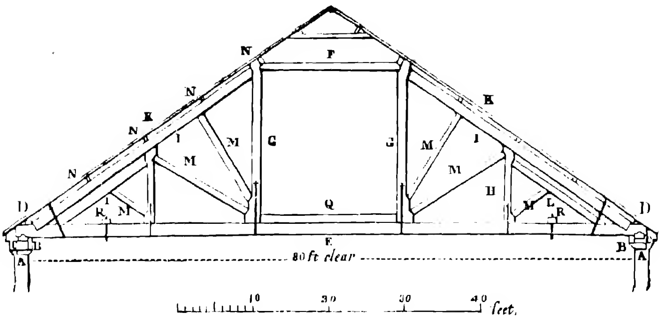


Fig. 38.

	Inch. scantling.
A, is an oak corbel	9 × 5
B, Inner plate.	9 × 9
C, Wall plate.	8 × 5½
D, Pole plate.	7 × 5
E, Tie-beam	15 × 15
F, Straining beam	12 × 9
G, Oak king-post (in the shaft)	9 × 9
H, Oak queen-post (in the shaft	7 × 9
I, Principal rafters.	9 × 9
K, Common ditto	4 × 2½
L, Principal braces.	9 and 6 × 9
M, Common ditto	6 × 9
N, Purlins	7 × 5
Q, Straining sill	5½ × 9

The roof is a fine specimen of English carpentry, and is one of the boldest and lightest roofs in Europe. The straining sill Q gives a firm abutment to the principal braces, and the space between the posts is 19½ feet wide, affording roomy workshops for the carpenters and other workmen connected with a theatre. The contrivance for taking double hold of the wall, which is very thin, is excellent. There is also added a beam (marked R), bolted down to the tie-beams. The intention of this was to prevent the total failure of so bold a trussing, if any of the tie-beams should fail at the end by rot.

Akin to this is Fig. 39,* the roof of Drury Lane theatre, 80 feet 3 inches in the clear, and the trusses 15 feet apart, constructed by Mr. Edward Grey Saunders.

	Inch. scantling
A, Tie-beams	10 × 7
B, Rafters	7 × 7
C, King-posts	12 × 7
D, Struts	6 × 7
E, Purlins	9 × 6
G, Pole plates	6 × 6
I, Common rafters	6 × 4
K, Tie-beam to the main truss	15 × 12
L, Posts to ditto	15 × 12
M, Principal braces to ditto	14 and 12 × 12
N, Struts	8 × 12
P, Straining beams	12 × 12

The main beams are trussed in the middle space with oak trusses 5 inches square. This was necessary for its width of 32 feet, occupied by the carpenters, painters, &c. The great space between the trusses affords good store-rooms, dressing-rooms, &c.

It is probable that this roof has not its equal in the world for lightness, stiffness, and strength. The main trusses are so judiciously framed, that each of them will safely bear a load of near 300 tons; so it is not likely that they will ever be quarter loaded. The division of the whole into three parts makes the exterior roofings very light. The strains are admirably kept from the walls, and the walls are even firmly bound together by the roof. They also take off the dead weight from the main truss one-third.

The intelligent reader will perceive that all these roofs are on one principle, depending on a truss of three pieces and a straight tie-beam. This is indeed the great principle of a truss, and is a step beyond the roof with two rafters and a king-post. It admits of

* See also Atlas, Plate IV.

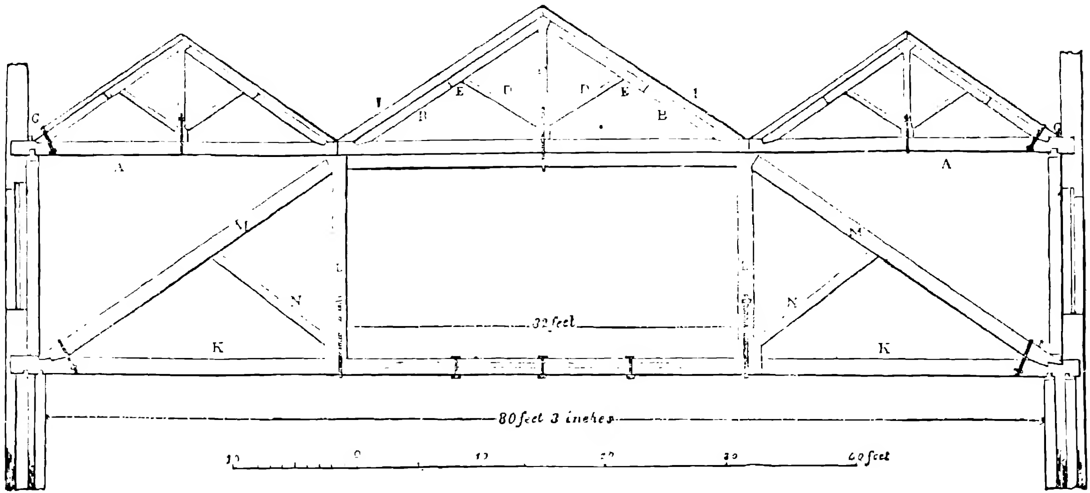


Fig. 39.

much greater variety of forms, and of greater extent. We may see that even the middle part may be carried to any space, and yet be flat at top; for the truss beam may be supported in the middle by an inverted king-post (of timber, not iron), carried by iron or wooden ties from its extremities: and the same ties may carry the horizontal tie-beam K; for till K be torn asunder, or M, M, and P be crippled, nothing can fail.

The roof of St. Martin's church in the Fields is constructed on good principles, and every piece properly disposed. But although its span does not exceed 40 feet from column to column, it contains more timber in a truss than there is in one of Drury Lane Theatre. The roof of the chapel at Greenwich, that of St. Paul's, Covent Garden, that of Birmingham and that of Drury Lane Theatres, form a series gradually more perfect.

To avoid a large expanse of roof, the truss shown in Plate IV., Fig. 1 (Atlas), may be used for a span of 55 to 65 feet.

107. Roofs with Curved Ribs.—There is a considerable degree of difficulty in executing a roof when there are a great number of joints, and the timbers of large dimensions; and the shrinkage of the king or queen-posts often produces considerable derangements in the truss. It is obvious, that to make principal rafters in a continued series of pieces abutting end to end against one another would remedy these defects. These pieces would then form a kind of curve, and, according to the degree of neatness required, might be made regular, or left with projecting angles, as is shown by Fig. 1, Plate V.* These pieces might either be bolted, or mortised and put together with wooden keys, as represented in Fig. 2. The length of the

* See Atlas.

pieces would be determined by the form of the curve; crooked timber would be preferable for the ribs where it could be procured, as the joints should be as few as possible, and they should be crossed, like the joints in stone work.

Plate V., Fig. 3, shows a roof constructed in this manner. Each of the supports for the tie-beam marked S, S, &c., consists of two pieces, one put on each side of the rib, and notched both to the rib and to the tie-beam. The pieces are bolted together, as is shown by a section to a larger scale, through one of these pairs of suspending pieces, in Fig. 4. This plan of construction admits of a much firmer connection with the tie-beam than is procured by the ordinary mode, and the number of suspending pieces may be increased at pleasure. The best situation for the suspending pieces is at the joints of the curved rib.

The weight of the roof being very nearly uniformly distributed, the form of the curved rib should be a parabola; and as this curve is easily described with sufficient accuracy for this purpose, it is best to adopt it; because in that case, the strain from the weight of the roof and ceiling will have no tendency whatever to derange the form of the rib; and its depth will always be sufficient to withstand any partial force to which a roof is ever likely to be exposed. Consequently, when the rib is of a parabolic form, diagonal braces will be unnecessary as regards the constant strain; nevertheless, if they be added, they will increase the strength to resist any partial strain in a very considerable degree.

To construct the parabola, let AB, Fig. 5, be drawn for the upper side of the tie-beam, and AC, CB, for the under side of the common or small rafters. Then divide AC and CB each into the same number of equal parts (an even number is to be preferred); and join

the points 1 and 1, 2 and 2, &c.; then the curve formed by these intersecting lines will be the parabola required.

But it will be found that this curve scarcely differs from a circular arc that rises half the height of the roof: therefore either may be used.

If a lantern or any other structure is to be raised on the top, a hyperbolic curve should be adopted; which admits of a considerable increase of pressure at the crown. For an easy mode of drawing a hyperbola, see Tarn's "Practical Geometry."

Smaller roofs might be constructed in a similar manner, at a comparatively small expense. But in these, instead of forming the rib of short pieces, it might be bent by a method somewhat similar to that used for bending ship timber. If the depth of a piece of timber does not exceed a hundred and twentieth part of its length, it may be bent into a curve that will rise about one-eighth of the span without impairing its elastic force. And if two such pieces be laid one upon the other, and then bent together by means of a rope fixed at the ends, they may be easily brought to the form of the required curve, by twisting the rope as a stone sawyer tightens his saw, or as a common bow saw is tightened. The pieces may then be bolted together; and if this operation be performed in a workmanlike manner, the pieces will spring very little when the rope is gently slacked; and it is advisable to do it gradually, that the parts may take their proper bearing without crippling. Otherwise, a piece of about one-sixtieth part of the span in thickness may be sawn along the middle of its depth, with a thin saw, from each end towards the middle of the length, leaving a part of about 8 feet in the middle of the length uncut. The pieces may then be bent to the proper curve, and bolted

as before. In either case the rise of the ribs should be half the height of the roof; and they should be bent about one-fourth more, to allow for the springing back when the rope is taken off. A roof of this kind for a 30 feet span is shown by Plate V., Fig. 6.* The suspending pieces are notched on each side, in pairs, and bolted or strapped together, as shown by Fig. 4.

The advantages of this roof consist in the small number of joints in the truss, in being able to support the tie-beam at any number of points, in admitting of a firm and simple connection with the tie-beam, and in avoiding the ill effects attending the shrinking of king or queen-posts.

108. THE PROPORTIONS OF THE TIMBERS OF A ROOF depend so much on the design of the framing, that it would be impossible to furnish rules which should apply directly to all cases. Nevertheless, by considering a few combinations, the method that may be adopted will be seen, and consequently may be applied to designs made on other principles than those already shown.

THE KING-POST is intended to support the ceiling, and by means of the braces to support part of the weight of the roof. The weight suspended by the king-post will be proportioned to the span of the roof, and will be half the weight of the tie, the other half being carried by the walls.

QUEEN-POSTS AND SUSPENDING PIECES are strained in a similar manner to king-posts, but the load upon them is only proportional to that part of the length of the tie-beam held up by each suspending piece or queen-post; in queen-posts the part suspended by each is generally one-third the span, as one-third of the weight of the tie is borne directly by the walls.

* See Atlas.

A TIE-BEAM is affected by two strains—the one in the direction of the length from the thrust of the principal rafters; the other is a cross strain from its own weight and that of the ceiling below. In estimating the strength, the thrust of the rafters need not be considered when there is a ceiling to carry, because the beam must in that case be abundantly strong to resist this strain; and when a beam is strained in the direction of the length, it rather increases the strength to resist a cross strain. Therefore the pressure, or the weight supported by the tie-beam, will be proportional to the length of the longest part of it that is unsupported. But there are two cases—one where the weight is merely the weight of the ceiling; the other where there are rooms in the roof, in which case the scantling of the tie-beam must be that of a girder or binder of the same span (99).

In estimating the strength of PRINCIPAL RAFTERS, we may suppose them to be supported by struts, either at or very near all the points which the purlins rest upon. The pressure on a principal rafter is in the direction of its length, and is in proportion to the magnitude of the roof; but the effect of this pressure does not bear the same proportion to the weight when there is a king-post, as when there are queen-posts.

A STRAINING BEAM is the horizontal piece between the heads of the queen-posts, and the pressure is in the direction of its length, and is the same as that sustained by the rafters. In order that this beam may be the strongest possible, its depth should be to its thickness as 10 is to 7.

That part of a roof which is supported by a STRUT or BRACE is easily ascertained from the design, but the effect of the load must depend on the position of the brace. When it is square from the back of the rafter,

the strain upon it will be the least; and when it has the same inclination as the roof, the same strain will be thrown on the lower part of the principal rafter as is borne by the strut. If a piece intended for a brace, a principal rafter, or a straining beam, be curved, the convex side should be placed upwards.

The stress upon *purlins* is proportional to the distance they are apart; and the weight being uniformly diffused, the stiffness is reciprocally as the cube of the length, and the scantling may be found by the rules for binders (99).

Purlins should always be notched down upon the principal rafters, and should be put on in as long lengths as they can be conveniently got, as the strength is nearly doubled by this means. The old method of framing the purlins into the principal rafters, not only renders the purlins weaker, but also wounds the principal rafter, and consequently renders it necessary to make the rafters stronger.

There is no part of a roof so liable to fail as the purlins; indeed there are few cases where they have not sunk considerably; and in some instances so much as to deform the external appearance of the roof. Weak purlins might be much strengthened by bracing them—a practice which was once very common among the builders in this country. Blocks should be spiked to the upper face of the rafter, against which the side of the purlin can rest so as to be prevented from twisting.

COMMON RAFTERS are uniformly loaded, and the breadth need not be more than from 2 inches to 2½ inches. The strength may be ascertained from the rules for the stiffness of beams, as in the case of single-jointed floors (98).

Foreign fir of straight grain makes the best common rafters and purlins, because it is not so subject to warp

and twist with the heat of roofs in summer as oak; much, however, depends on the quality of the timber; oak from old trees often stands very well.

No general rules can be given for the scantlings of the timbers of framed roofs, but they must be calculated in each particular case by the method previously explained (79, 80). The following tables give the scantlings obtained by that method in roofs of various spans having a pitch of about 30° :—

SCANTLINGS OF FIR TIMBERS FOR KING-POST ROOFS.

Span.	Tie-beam.	King-post.	Principal rafter.	Struts.	Purlins.	Common rafters.
Ft.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	7 × 3	2½ × 3	4½ × 3	3½ × 3	7 × 3	3½ × 2
24	8 × 3½	3½ × 3	3½ × 4½	3½ × 3½	8 × 3	4½ × 2
28	9 × 4½	4½ × 2½	4½ × 4½	4½ × 3	9 × 4	5 × 2½
30	9 × 5	5 × 3	5 × 5	5 × 3	9 × 5	5½ × 2½

The scantlings of the common rafters here given are on the supposition that there is only one purlin on the centre of the principal rafter; but if there are more purlins the scantling of the common rafters can be reduced. If there is no ceiling to be carried by the tie-beam, its depth may be reduced to one-half that given in the tables.

SCANTLINGS OF FIR TIMBERS FOR QUEEN-POST ROOFS.

Span.	Tie-beam.	Queen-post.	Principal rafter.	Straining beam.	Struts.	Purlins.	Common rafters.
Ft.	Ins.	Ins	Ins.	Ins.	Ins.	Ins.	Ins.
32	7 × 4	4 × 3	4½ × 4	6 × 4	4 × 3	7 × 3	3½ × 2
36	8 × 4½	4½ × 3	5 × 4½	7 × 4½	4½ × 3	8 × 3	4 × 2
40	9 × 5	5 × 3½	5½ × 5	8 × 5	5 × 4	9 × 4	4½ × 2
45	9 × 5½	5½ × 4	6 × 5½	9 × 5½	5½ × 4½	9 × 5	5 × 2½
50	11 × 6	6 × 5	7 × 6	10 × 6	6 × 5	9 × 6	5½ × 2½

These scantlings for common rafters are given on the supposition that there are only two intermediate purlins on each side of the roof, at equal distances apart; if there are more purlins, the scantlings of the common rafters can be reduced.

The strength of common rafters, whether attached to a truss or used alone and merely fixed at top and bottom, should be about one-half that given for the bridging joists of a floor, varying with the length of bearing without intermediate support; if a very heavy covering has to be borne, the strength must be proportionately increased, but as the pressure of the wind is the chief load to be sustained, the kind of covering makes but little difference in the strain.

109. A DOME or CUPOLA is a roof, the base of which is a circle, an ellipsis, or a polygon; and its vertical section a curved line, concave towards the interior. Hence, domes are called circular, elliptical, or polygonal, according to the figure of the base. The most usual form for a dome is the spherical, in which case its plan is a circle, the section a segment of a circle. The top of a large dome is often finished with a *lantern*, which is supported by the framing of the dome.

The interior and exterior forms of a dome are not often alike, and in the space between, a staircase to the lantern is generally made. According to the space left between the external and internal domes, the framing must be designed. Sometimes the framing may be trussed with ties across the opening; but often the interior dome rises so high that ties cannot be inserted.

Accordingly, the construction of domes may be divided into two cases, viz., domes with horizontal ties, and those not having such ties.

A truss for a dome where horizontal ties can be

inserted is shown by Fig. 1, Plate VII.* In this figure AA is the tie; BB posts, which may be continued to form the lantern; C, C are continued curbs in two thicknesses, with the joints crossed and bolted together; DD, a curved rib to support the rafters. This design is calculated for a span of about 60 feet, and may be extended to 120 feet. Two principal trusses may be placed across the opening, parallel to each other, and at a distance equal to the diameter of the lantern apart, as AB, CD, Fig. 2,† with a sufficient number of half-trusses to reduce the bearing of the rafters to a convenient length. Or, the two principal trusses may cross each other at right angles in the centre of the dome, the one being placed so much higher than the other as to prevent the ties interfering. This disposition is represented in Fig. 3; and is the same that is adopted for the Dôme des Invalids, at Paris, of which the external diameter is nearly 90 English feet.

The construction of domes without horizontal cross-ties is not difficult, where there is sufficient tie round the base. The most simple method, and one which is particularly useful in small domes, is to place a series of curved ribs so that the lower ends of those ribs stand upon the curb at the base, and the upper ends meet at the top, with diagonal struts between the ribs.

When the pieces are so long, and so much curved that they cannot be cut out of timber without being cut across the grain so much as to weaken them, they should be put together in thicknesses, with the joints crossed and well nailed together; or, in very large domes, they should be bolted or keyed together. The manner of forming these ribs has been already described as applied to roofs (105). This method of making curved ribs in thicknesses has been used in the con-

* See Atlas. † Ibid.

struction of centres for arches from the earliest period of arch building; and it was first applied to the construction of domes by Philibert de Lorme, who gives the following scantlings for different sized domes :—

For domes	of	24	feet diameter,	8	inches	by	1 inch.
,,	,,	36	,, ,,	10	,,		$1\frac{1}{2}$,,
,,	,,	60	,, ,,	13	,,		2 ,,
,,	,,	90	,, ,,	13	,,		$2\frac{1}{2}$,,
,,	,,	108	,, ,,	13	,,		3 ,,

These ribs are formed of two thicknesses, of the scantlings given above, and are placed about two feet apart at the base. The rafters are notched upon them for receiving the boarding, and also horizontal ribs are notched on the inside, which gives a great degree of stiffness to the whole. Fig. 4* is a section of a dome constructed in this manner; and Fig. 5† a projection of a part of the dome, with the rafters and inside ribs.

If the dome be of considerable magnitude, the curve of equilibrium should pass through the middle of the depth of the ribs, particularly if a heavy lantern rests upon them. Otherwise the curve must fall within the curve of equilibrium, and struts must be placed between the ribs, to prevent them bending in. Or, if it be necessary for the external appearance of the dome that the curvature of the ribs should be without the curve of equilibrium, then an iron hoop may be put round about one-fourth of the height to prevent the dome bursting outwards. This latter method was adopted in the external dome of the Church della Salute, at Venice, the outside dimensions of which are 80 feet diameter, 40·5 feet high, and the lantern 39·5 feet high; but the lantern is supported by a brick dome, which is considerably below the wooden one. The ribs of this dome are ninety-six in number, and each rib is in four thick-

* See Atlas, Plate VII. † Ibid.

nesses; the four together making 5·5 inches, so that each rib is 8·5 inches by 5·5 inches. The iron hoop is 4·5 inches wide, and half an inch in thickness, and is placed at one-third of the height of the dome.

When a dome is intended to support a heavy lantern, it may require the principal ribs to be stronger than can be obtained out of a piece of timber; but the framing may always be made sufficiently strong by using two ribs, with braces between, and tied together with radial pieces across from rib to rib. A truss of this form is shown by Fig. 6, which would sustain a very heavy lantern, if the curve of equilibrium were to pass in the middle between the ribs, as the dotted line does in the figure.

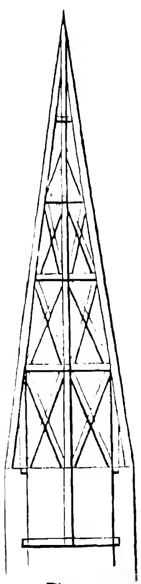


Fig. 40.

Where a light dome is wanted, without occupying much space, the ribs may be placed so near to each other that the boards may be fixed to them without rafters, or short struts may be put between the ribs, as shown by Fig. 7.

110. Conical Roofs and Spires are framed in a somewhat similar manner to cupolas, a curb being securely fixed on the top of the wall from which the spire is to spring, and into this are framed the main ribs following the slope of the spire; if it is octagonal on plan, there are eight main ribs, one at each angle; these ribs are all framed at their upper ends into a vertical mast, which goes down the centre of the structure, and is secured by horizontal ties at the base, which are framed into the curb; horizontal ribs or purlins are introduced at several places up the spire, according to the height, and framed into the sides of

the main ribs (Fig. 40). In very lofty spires there will also be cross strutting, to prevent the framework from bending by the force of the wind. Intermediate ribs or rafters are framed into the purlins, and on these the boarding is nailed to receive the covering. When properly framed, and of well-seasoned timber, these spires will last for centuries.

Numerous examples of ancient wooden spires, or *flèches*, are to be found on the Continent, especially in Germany. In England the most remarkable is that of Chesterfield Church, which is covered with lead, and has become warped and twisted by the action of the sun, which is more powerful on the south than on the other sides. In modern times several timber spires have been built, as that of All Saints' Church, Margaret Street, London, which stands on a brick tower, and the top is 220 feet from the ground.

110*a*. Rules for Scantlings of Roof Timbers.—The following formulæ and rules for finding the scantlings of the timbers of King- and Queen-post trusses of fir, where the height at the centre is one-fourth of the span, or the angle of pitch is 27°, are taken from the sixth edition of *Tredgold's Carpentry*. The principals are supposed to be placed 10 feet apart, and the load per square foot of roofing to be 66 lbs.

King-posts.—The strain on these beams is half the weight of the tie-beam and any load it has to carry, together with the vertical component of the pressure down the braces which support the middle of the rafters, which latter pressure increases with the angle of inclination of the brace to the horizontal. Let S be the span of the roof in feet, B and D the scantling in inches of the smallest part of the post; then if any

two of these dimensions are known, the third can be determined from the equation

$$B \,.\, D = \tfrac{1}{3} S$$

when the tie-beam carries a ceiling only.

Where the tie-beam carries a floor as well as a ceiling,

$$B \,.\, D = S$$

RULE.—When the tie-beam carries a ceiling only, one-third of the span, in feet, divided by the breadth of the king-post, in inches, will give its thickness in inches. When the tie-beam carries a floor as well as a ceiling, the span, in feet, divided by the breadth of the king-post, in inches, will give its thickness in inches.

Queen-posts. — Each of these beams is supposed to support one-third the load on the tie-beam, and also the vertical component of the pressure down one of the braces which support the rafters. The scantling is determined in the case when a tie-beam carries a ceiling only, from the equation

$$B \,.\, D = \tfrac{1}{7} S$$

If a floor is supported by the tie-beam, as well as a ceiling, then

$$B \,.\, D = \tfrac{3}{5} S$$

RULE.—When the tie-beam carries a ceiling only, one-seventh of the span, in feet, divided by the breadth of the queen-post, in inches, will give its thickness in inches. When the tie-beam carries a floor as well as a ceiling, three-fifths of the span, in feet, divided by the breadth of the queen-post, in inches, will give its thickness in inches.

Tie-beams.—To find the scantling, when the tie-beam has to support a ceiling only, let L be the longest

unsupported part, in feet; B, the breadth, and D, the depth, in inches. When any two of these dimensions are given, the third can be found from the equation,

$$B \,.\, D^3 = L^3$$

RULE.—The length of the longest unsupported part, in feet, divided by the cube-root of the breadth, in inches, gives the depth in inches. Or, the cube of the above length, in feet, divided by the cube of the depth, in inches, gives the breadth in inches.

When the tie-beam carries a floor, as well as a ceiling,

$$B \,.\, D^3 = 10\, L^3$$

RULE.—The length of the longest unsupported part, in feet, divided by the cube-root of the breadth, in inches, and the quotient multiplied by 2·2, gives the depth in inches. Or, ten times the cube of the length, divided by the cube of the depth, gives the breadth.

Principal Rafters.—The strain on these beams is considered as entirely compressive, and to act on them as on a long pillar, the only transverse strain which they have to bear being that arising from their own weight. The equation for their sectional area in a king-post roof is

$$B \,.\, D = \sqrt{\cdot 024\, S^3}$$

and in queen-post roof the equation is

$$B \,.\, D = \sqrt{\cdot 0126\, S^3}$$

To find the scantling in the case of a king-post roof, we have the following

RULE.—Multiply the cube of the span, in feet, by ·024, and the square-root of the product will be the sectional area of the rafter in inches; which divided by the breadth will give the depth, or by the depth will give the breadth.

To find the scantling of the principal rafters of a queen-post roof, use the multiplier ·0125 instead of ·024 in the above rule.

Straining-beam.—The strain in this beam is also considered as wholly compressive, as in the rafters, and the equation for its sectional area is

$$B \,.\, D = \sqrt{\cdot 028\, S^3}$$

To find the scantling of this beam in a queen-post roof, whose unsupported length is one-third of the span, we have the following

RULE.—Multiply the cube of the span of the roof by ·028, and the square-root of the product will be the sectional area of the beam in inches; which divided by the breadth will give the depth, or by the depth will give the breadth.

Struts and Braces.—These beams are considered as under compression only, which acts down their axes, and the equation for sectional area in a king-post roof is

$$B \,.\, D = \sqrt{\cdot 0073\, S^3},$$

and in a queen-post roof it is

$$B \,.\, D = \sqrt{\cdot 0023\, S^3}$$

For the scantlings of these beams we have the following

RULE.—Multiply the cube of the span, in feet, by ·0073, in the case of a king-post roof, and by ·0023 in that of a queen-post roof; then the square-root of the product is the sectional area of the strut in inches.

Purlins.—The scantling of these will depend upon the distance they are placed apart, and their length of bearing. Let x and l be these dimensions, in feet, B and D the breadth and depth, in inches; then,

$$B \,.\, D^3 = \cdot 367\, x \,.\, l^3$$

Or, if we put $l = 10$ feet, then,

$$B \,.\, D^3 = 367\, x$$

RULE.—Multiply the distance apart of the purlins, in feet, by 367, and divide by the cube of the depth in inches; the quotient is the breadth in inches. Or, divide 367 times the distance apart by the breadth; the cube-root of the quotient is the depth.

Common Rafters.—The strain on these beams being chiefly transverse, as in floor-joists, if l is the distance apart of the purlins, or clear bearing of the rafters, in feet, then the scantling is obtained from the equation

$$B \, . \, D^3 = \cdot 367 \, l^3$$

RULE.—Multiply the cube of the length between the purlins, in feet, by ·367, and divide by the cube of the depth in inches; the quotient is the breadth in inches. Or, multiply the cube of the length by ·367, and divide by the breadth; the cube-root of the quotient is the depth.

SECTION III.—*The Construction of Partitions and Frame Houses.*

111. PARTITIONS, in carpentry, are frames of timber for dividing the internal parts of a house into rooms; they are usually lathed and plastered, and sometimes the spaces between the timbers are filled with brick-work, which is termed brick-nogging.

In modern carpentry there is no part of a building so much neglected as the partitions. A square of partitioning is of considerable weight, seldom less than half a ton, and often much more; therefore a partition should have an adequate support: instead of which it is often suffered to rest on the floor, which, of course, settles under a weight it was never intended to bear, and the partition breaks from the ceiling above.

If it be necessary to support a partition by means of the floors or roof, it should rather be strapped to the floor or roof above it, than be suffered to bear upon the floor below; because in that case the cracks along the cornice would be avoided; and in such cases the timbers of the floor or roof must be made stronger. A partition ought, however, to be capable of supporting its own weight; for even when doorways are so placed that a truss cannot be got the whole depth, it is almost always possible to truss over the heads of the doors.

Partitions that have a solid bearing throughout their length do not require any braces; indeed they are better without them, as it is easy to stiffen them by means of struts between the uprights, and thus the shrinking and cross strains occasioned by braces are avoided. When braces are introduced in a partition they should be disposed so as to throw the weight upon points which are sufficiently supported below, otherwise they do more harm than good.

But though it be often practicable to give a partition a solid bearing throughout, it is better not to do so, because all walls settle; therefore the partition should always be supported only by the walls it is connected with, in order that it may settle with them. If the partition have a solid bearing, and the walls settle, fractures must necessarily take place.

Also, when a partition is supported at one end by the wall of a high part of the building, and by the wall of a lower part at the other end, it will always crack, either close by the walls, or diagonally across.

In a trussed partition the truss should have good supports, either at the ends or other convenient places, and the framing should be designed accordingly; that is, so that the weight may not act on any other points

than those originally intended to bear it. The best points of support are the walls to which the plastering of the partition joins.

Partitions are made of different thicknesses, according to the extent of bearing; for common purposes, where the bearing does not exceed 20 feet, 4 inches is sufficient; or generally the principal timbers may be made of the following scantlings:—

4 inches	by	3 inches	for a bearing	not	exceeding	26 feet.
5	,,	3½	,,	,,	,,	30 ,,
6	,,	4	,,	,,	,,	40 ,,

And partitions should be filled in with as thin stuff as possible, provided it be sufficient to nail the laths to. Two inches is quite a sufficient thickness. When these filling-in pieces are in long lengths—that is, when they exceed 3 or 4 feet—they should be stiffened by short struts between them; or, which is much better, we may notch a continued rail across the uprights, nailing it to each.

The thicknesses above-mentioned apply only to partitions that have no other than their own weight to bear. When a floor is to be supported by a partition, it must be prepared for that purpose. It would, however, be impossible to give any rules for such partitions, as the design must be varied according to circumstances, which differ so materially in almost every case as to render particular rules useless.

When partitions of considerable strength are required, another simple method of constructing them may be employed with advantage, particularly where it is desirable to prevent the passage of sound.

Let the truss be formed of such strong timbers as may be necessary, nearly as in the usual method; but instead of filling in the pieces for nailing the laths to between the timbers, let them be nailed, in the manner

of battens, upon each side of the truss. A partition done in this manner occupies a little more space, but to compensate for this, it has the advantage of strength and lightness, besides preventing the passage of sound better than the common mode of construction.

The following data will assist in forming an estimate of the pressure on the framing of partitions:—

The weight of a square of partitioning may be taken at	from	1,480	pounds to	2,000	pounds per square.
The weight of a square of single-joisted flooring, without counter-flooring . .	,,	1,260	,,	2,000	,,
The weight of a square of framed flooring, with counter-flooring . . .	,,	2,500	,,	4,000	

As great nicety is not required in calculating the scantlings, the highest numbers may be taken for long bearings, and the lowest for short ones; as the one gives the weight in large mansions, the other that in ordinary houses.

The shrinkage of timbers, and still more often imperfect joints, cause considerable settlements to take place in partitions, and consequently cracks in the plastering; therefore it is essential that the timber should be well seasoned, and also that the work should be well framed, as a slight degree of settlement in a partition is attended with worse consequences than those produced by a like degree of settlement in any other piece of framing.

Fig. 1* shows a design for a trussed partition with a doorway in the middle; the tie or sill is intended to pass between the joisting under the flooring boards. The strongest positions for the inclined pieces of the truss is shown by the figure, as the truss would have been much weaker with the same quantity of materials,

* See Atlas, Plate VIII.

if they had been placed in the position shown by the dotted lines. The inclination of the trussing pieces should never greatly differ from an angle of 40 degrees with the horizon. The horizontal pieces, *a a*, are intended to be notched into the uprights, and nailed: in partitions for principal rooms, one on each side might be used.

When a doorway is near to the side of a room, which is often necessary, in order to render the room either convenient or comfortable, the partition should be trussed over the top of the door, as shown in Fig. 2. The posts, A, B, should be strapped to the truss, and braces may be put in the lower part of the truss in the common way; but it would be better to halve those braces into the uprights, which would bind the whole together.

In order to save straps, the posts, A, B, are often halved into the tie CD; in that case, the tie should be a little deeper; and as the tie may be always made strong enough to admit of halving, perhaps this is the best method.

112. FRAME HOUSES are rectangular structures formed entirely of timber framing, very much on the same principle as quarter partitions, except that they have to carry the weight of the roof, while their own weight is borne by the ground on which they are placed. These houses are made so that they can be readily taken to pieces and removed to another locality, and the mode of framing is arranged especially with this in view. The framing consists of four strong upright posts, which form the angles of the structures, and are framed into horizontal heads and sills; the heads are further strengthened by intermediate uprights on each side; these help to support the rafters of the roof, which are notched and spiked on the heads as upon a wall-plate.

Intermediate horizontal rails are framed into the uprights to prevent bending, and the spaces are filled with quartering, as in a framed partition. The walls are usually covered on the outside with weather-boarding, and on the inside with lath and plaster or matched-boarding. The roof is formed in the usual manner with rafters and collars or tie-beams, and covered with weather-boarding, slate, or zinc. The sills should not be allowed to rest on the earth, but upon a few courses of bricks or stones, so as to prevent them from rotting. The internal divisions are made by means of ordinary quarter partitions.

The ancient timber houses found in some parts of England and the Continent are constructed in a somewhat similar manner, but with very strong timbers, as they consist of several stories of rooms. The upper stories generally overhang the lower ones, the framing being corbelled out by means of the joists or girders of the floor, which are carried the required distance beyond the wall of the lower storey, and on these the sill of the framing for the upper storey is laid. The main timbers were usually left exposed on the outside, and the spaces between filled with lath and plaster upon intermediate quarterings.

CHAPTER IV

CENTERINGS, BRIDGES, JOINTS, SCARFINGS, SHORING, &c.

Section I.—Centerings.

113. A Centre is a timber frame, or set of frames, for supporting the arch-stones of a bridge during the construction of the arch. The qualities of a good centre consists in its being a sufficient support for the weight or pressure of the arch-stones, without any sensible change of form throughout the whole progress of the work, from the springing of the arch to the fixing of the key-stone. It should be capable of being easily and safely removed, and designed so that it may be erected at a comparatively small expense.

In navigable rivers, where a certain space must be left for the passage of vessels, and in deep and rapid rivers, where it is difficult to establish intermediate supports, and where much is to be apprehended from sudden floods, the frames should span the whole width of the archway, or be framed so as to leave a considerable portion of the archway unoccupied. In such cases a considerable degree of art is required to make the centre an effectual support for the arch-stones, particularly when the arch is large. But in narrow rivers, and in those where the above-mentioned inconveniences do not interfere with the work, the framing may be constructed upon horizontal tie-beams, supported in

several places by piles, or frames fixed in the bed of the river; and the construction is comparatively easy.

In large arches, when the arch-stones are laid to a considerable height, they often force the centre out of form, by causing it to rise at the crown; and it is sometimes necessary to load the centre at the crown to prevent such rising; but this is a very imperfect remedy.

Centres are composed of several separate vertical frames or trusses, connected together by horizontal ties, and stiffened by braces. When the frames have to span the whole width of the archway, the offsets of the stonework afford a most substantial abutment for the support of the centre. The frames or trusses of centres are generally placed from four to six feet apart, according to their strength, and the pressure they have to support. In general there is one frame under each of the external rings of arch-stones, and the space between is equally divided by the intermediate frames.

A bridge of three arches will require two centres, one of five arches requires three centres, &c.

Before proceeding to investigate the disposition and stiffness of centres, the point must be determined at which the arch-stones first begin to press upon the centre; and also the pressure upon it at different periods of the formation of the arch. It has been found by experiment, that a stone placed upon an inclined plane does not begin to slide till that plane has an inclination of about 30 degrees from the horizontal plane; and till a stone would slide upon its joint, or bed, it is obvious that it would not press upon the centre. Also, when a hard stone is laid with a bed of mortar it will not slide till the angle becomes from 34 to 36 degrees. A soft stone bedded in mortar will stand when the angle which the joint makes with the

horizon is 45 degrees, if it absorb water quickly; because in that case the mortar becomes partially set. Similar results have been obtained by other experimentalists; therefore we may consider the pressure in general to commence at the joint which makes an angle of about 32 degrees with the horizon.

This angle is called the angle of repose, and if we suppose the pressure to be represented by the radius, the tangent of this angle will represent the friction; hence, considering the pressure as unity, the friction will be 0·625.

The next course above the angle of repose will press upon the centre, but only in a small degree; and the pressure will increase with each succeeding course. The relation between the weight of an arch-stone, and its pressure upon the centre, in a direction perpendicular to the curve of the centre, may be determined from the following equation: W (sin. a — f cos a) = P.

Where W is the weight of the arch-stone, P = the pressure upon the centre, f = the friction, and a = the angle which the plane of the lower joint of the arch-stone makes with the horizon.

When the angle which the joint makes with the horizon is . .	34 degrees,	P = ·04 W
„ „ „	36 „	P = ·08 W
„ „ „	38 „	P = ·12 W
„ „ „	40 „	P = ·17 W
„ „ „	42 „	P = ·21 W
„ „ „	44 „	P = ·25 W
„ „ „	46 „	P = ·29 W
„ „ „	48 „	P = ·33 W
„ „ „	50 „	P = ·37 W
„ „ „	52 „	P = ·40 W
„ „ „	54 „	P = ·44 W
„ „ „	56 „	P = ·48 W
„ „ „	58 „	P = ·52 W
„ „ „	60 „	P = ·54 W

But when the plane of the joint becomes so much inclined that a vertical line passing through the centre

of gravity of the arch-stone does not fall within the lower bed of the stone, the whole weight of the arch-stone may be considered as resting upon the centre, without material error. We have thus an easy method of estimating the weight upon a centre, at any period of the construction, or when any portion of the arch-stone is laid, as well as when the whole weight it has to sustain is upon it.

It is evident from an inspection of the table, that the pressure increases very slowly till the joint begins to make a considerable angle with the horizon; and it is of importance to bear this in mind in designing centres, because the strength should be directed to the parts where the strain is greatest. For instance, at the point where the joint makes an angle of 44 degrees with the horizon, the arch-stone only exerts a pressure of one-fourth of its weight upon the centre; where the angle of the joint is 58 degrees, the pressure exceeds half the weight; but near to the crown the stones rest wholly upon the centre. Now it would be absurd to make the centre equally strong at each of these points; besides, by such a method there would not be the means of applying the strength where it is really required, without interfering with ties and braces, which are only an incumbrance to the framing.

When the depth of the arch-stone is nearly double its thickness, the whole of its weight may be considered to rest upon the centre at the joint which makes an angle of about 60 degrees with the horizon. If the length be less than twice the thickness, it may be considered to rest wholly upon the centre when the angle is below 60 degrees; and if the length exceed twice the thickness, the angle will be considerably above 60 degrees before the whole weight will press upon the centre.

When the arch-stones are small, the pressure upon

the centre is greater than when they are large; and as an arch-stone will seldom be smaller than would extend one degree of the arch, the pressure in that case may be assumed as sufficiently accurate: the error being always in excess till the arch-stones are less than one degree each.

114. The Design of Frames for Centres.—There are two things which require particular attention; the centre should be sufficiently strong to support any part, or the whole of the pressure; and it should be capable of supporting any part without a sensible change of form. To accomplish the first object, the strains must not act very obliquely upon the supporting pieces; and the magnitude of the parts must be proportional to the strain upon them. The second object will be obtained by disposing the parts so that the stress may prevent any part rising, instead of causing it to rise, as is too commonly the case in centres.

Centering for arches of small span is easily managed; and when it is possible to obtain intermediate supports at a comparatively small expense, even large centres are not difficult. The centering of Conon Bridge, of which the span is 65 feet, and rise 21·8 feet, is a good example of this kind of construction. See Atlas, Fig. 1, Plate IX.

Smeaton designed the centre, Fig. 3, Plate VIII. (Atlas), for Coldstream Bridge, which was of stone, 25 feet wide from outside to outside; the centering consisted of five frames, or ribs, framed in the manner represented in Fig. 3. The span of the centre arch was 60 feet 8 inches, and the dimensions of the principal timbers are figured upon the design.

But where intermediate supports cannot be obtained, centres require to be constructed with more care; more attention is also necessary in forming the design. It

is obvious that laying a load upon the haunches must have a tendency to raise the centre at the crown, unless the frame be so contrived that it cannot rise there under the effect of any force that it may have to sustain at the haunches. This principle has not been properly understood by some engineers, and some of their centres have, in consequence, undergone a change of form with every course of stones that was laid upon them. We cannot perhaps show better the importance of the principle of preventing any change of form by the disposition of the framing, than by pointing out the defects of the centre designed by Perronet for the Bridge of Neuilly, and comparing it with some others that have been employed. Fig. 2, Plate IX. (Atlas), represents the centre of the Bridge at Neuilly. It is obvious that such a centre, loaded at A and B, must rise at C; and the timbers being nearly parallel, the strains produced by a weight resting on any point must have been prodigious; consequently, the yielding at the joints was very considerable. It is a kind of framing well enough adapted to support an equilibrated load, distributed over its whole length; but is one of the worst that can be adopted for a centre, or for supporting any variable load. It must have consumed an immense quantity of timber without possessing the advantage of connection. The quantity is crowded into so small a space that it has a light appearance, and consequently has obtained the approbation of those who are incapable of penetrating further than the apparent surface of the things they pretend to examine. The centres for the bridges of Nogent, Cravant, St. Maxence, and Nemours, were designed on similar principles, and were found to be equally defective.

Fig. 3 represents the centre of Waterloo Bridge. In this centre, by a better disposition of its timbers, a

load at A could not cause the centre to rise at C, without reducing the length of the beam DE, and the one opposite to it. There is an excess of strength in some of its parts, and it is complicated in the extreme; but on the whole it is a very judicious combination. The centre of the late Blackfriars Bridge appears to have been taken as the ground-work; and there are some improvements, both in form and construction, which do much credit to the able engineer who made them.

Let the line ACA′, Fig. 1, Plate X., represent the curve of an arch; and let us suppose the arch-stones to begin to press upon the centre at B, B′, where the joints make an angle of 32 degrees with the horizontal plane; and that the laying of the arch-stones proceeds alike on each side. Now if two trussed frames, EDH, E′D′H, abut against each other at C, the point C cannot rise in a sensible degree from the pressures at D, D′, and much additional security may be obtained by adding the piece FF′, with the pieces FI, F′I′.

The framing of this centre commences on each side, nearly at the point where the arch-stones first begin tc press upon the centre; the curved rib must be strong enough to bear the parts between BD and DC, but the bearings may be shortened by making the abutting blocks at D, D′ longer. The beams EC, E′C will act as ties till the arch-stones are laid beyond the points D, D′; they will then begin to act as struts, and will continue to act as struts after that, till the whole is laid.

This disposition cannot be employed where the span is large, because it then requires very long pieces of timber; and the points of support for the curved rib become too far apart to be supported by timbers of the usual dimensions.

Let the built beams EF, FF′, and F′E′, Fig. 85, Plate X., be each trussed, and abut against each

other at F and F′; then it is obvious, that when the loads press equally at D, D′, they will have no tendency to raise the beam FF′ in the middle, unless it be not sufficiently strong to resist the pressure in the direction of its length; and as it is easy to give it any degree of strength that may be required, a centre of this form may, with a little variation in the trusses, be applied with advantage to any span which will admit of a stone bridge. When timber is not to be had of sufficient length, the beams EF, FF′, and F′E′, may be built in the manner directed for building beams.

In the new London Bridge the arches are of very considerable span, the centre one being 150 feet, with a rise of only 29·5 feet; but by supporting the centre from the bed of the river, the skill required to span a large opening was avoided. The ribs consisted of trussed frames, and were supported by well-driven piles, so as to leave the central part of the arch open for the navigation.

115. Construction of Centres.—The principal beams of a centre should always abut end to end when it is possible. It is a very good method, where timbers meet at an angle, to let them abut into a socket of cast iron, as has been done in the centre of Waterloo Bridge. (See Fig. 3, Plate IX. Atlas.) The timbers should intersect one another as little as possible, as every joining causes some degree of settlement, and halving the timbers together always destroys nearly half their strength. The pieces which tend towards the centre, and which perform a similar office to the king-post of a roof, should be notched upon the framing; and they should be in pairs, that is, one on each side of the frame, and well bolted together. Most of the braces may also be applied in the same manner with much advantage. Ties should be continued across the frames in different parts, par-

ticularly at any point where many timbers meet; and diagonal braces across the frames are also necessary, to secure them from lateral motion.

The frames or principal supports of a centre should be placed upon double wedges, or sometimes they may be placed upon blocks with wedge-formed steps cut in them; and when the centre is to be eased, the wedges, or wedge-formed pieces, are driven back so far as to suffer the centre to descend regularly. This operation should be very leisurely performed, in order that the arch, in taking its proper bearing, may not acquire any sensible degree of velocity, as it would be a dangerous experiment to let it settle too rapidly.

The centre should always be eased a little, as soon as the arch is completed, in order that the arch-stones may take their proper bearings before the mortar becomes hard. If the mortar be suffered to dry before the centre be lowered, the arch will break at the joints in settling, and the connection of the arch will be destroyed.

In small centres the wedges are driven back with mauls, men being stationed at each pair of wedges for that purpose. But in larger works a beam is mounted, as a battering ram, to drive the wedge-formed blocks back. Before driving back the wedges, it is a good precaution to mark them, so that it may be easy to ascertain when they are regularly driven.

The centres of the late Blackfriars Bridge and of Waterloo Bridge were placed upon blocks, with wedge-formed steps cut in them, as is shown in Fig. 3, Plate IX. Another method consists in forming the steps on beams that reach across the whole width of the bridge, passing between the feet of the trussed frames and the posts that support them. In Fig. 1, Plate X., the centres are supposed to be done in this manner. The frames being

thus placed upon continued wedges, the centre may be struck without its being necessary to have workmen beneath: it is therefore less dangerous, and can be done with a less number of men.

In the erection of the Chester Bridge, finished in 1832, an entirely different principle was adopted in the construction and the mode of relieving the centre. This arch is the segment of a circle of 140 feet radius; the span is 200 feet, and the rise 42 feet. The centre consisted of six ribs in width, and the span of the arch was divided into four spaces, by means of three nearly equidistant piers of stone built in the river, from which timbers spread like a fan towards the soffit, so as to take their load endwise. The lower extremity of these radiating beams rested on cast-iron shoe-plates on the tops of the piers, and their upper ends were bound together by two thicknesses of 4-inch planking, bending round as nearly as they could be made in the true curve of the arch. On the rim thus formed, the ledging or covering, which was 4½ inches thick, was supported over each rib by a pair of folding wedges 15 or 16 inches long by 10 or 12 inches in breadth, and tapering about 1½ inch: for every course of arch-stones in the bridge, therefore, there were six pairs of striking wedges. The horizontal timber in the centre was only 13 inches deep, and the six ribs were tied together transversely near the top by bolts of inch iron which passed through.

This centre thus differs essentially from any other hitherto employed; each rib, instead of forming one connected piece of frame-work, consists here of four independent parts, and little or no transverse strain has to be resisted. Moreover, as the wedges are in this construction borne by the centre, instead of the centre being borne by them, it is obvious that the

bearings may thus be gradually relieved or tightened at one place and slackened at another, according to the symptoms shown by the arch, as its support is removed, and the stone-work comes to its bearing. (For further information relative to this erection, see Vol. i. Trans. Inst. Civ. Eng. p. 207.)

116. Computing the Strength of Centres.—It fortunately happens that simple designs are best calculated for centres; for it would be very difficult to form anything like an accurate estimate of the strength of a complicated one. We will here show some approximate methods of fixing upon the proper scantlings for the timbers for the designs which have been given; and add to one of them some examples in numbers, which will serve to illustrate the subject.

In the centre, Fig. 1, Plate X., the stress may be considered, in as far as it tends to strain the frame EDH; also the stress upon the pieces EH, H′E′, when the whole load is upon them; and, lastly, the strain upon the posts GK, G′K′.

First, let the pressure of the arch-stones between B and C be calculated. Consider half this weight as collected at D, and acting in the direction DF, which will be sufficiently accurate for our present purpose. Then the strains in the directions of each of the beams composing the frame EDH can be found; and the dimensions of the pieces which would resist them are to be determined by the rules for the stiffness of beams.

Secondly, compute the pressure of the arch between D and C, and consider it as acting at C in a vertical direction; then the strain on the beams EH, H′E′, will be found by the rules above referred to.

Lastly, let the whole pressure of the arch-stones between B and C, together with half the weight of the centre itself, be considered as acting at the point E

in a vertical direction, and find the dimensions of the supports KG, K′G′, that would resist the pressure.

But in these calculations it must be observed, that if the length of any of the pieces in feet be not greater than 1·25 times the breadth, or least dimension in inches, it will cripple at the joint rather than bend. Thus, if a piece be 8 inches in breadth, then its length must be $1{\cdot}25 \times 8$, or 10 feet; otherwise it will sink at the joint rather than bend.

Therefore, when the length between the points where it is braced is less than in this proportion, instead of finding the scantlings by the rules for the stiffness of beams, they must be determined by the following rule:—

Rule. The pressure upon the beam in pounds divided by 1,000 gives the area of the piece in inches, or that of the least abutting joint, if that joint should not be equal to the section of the piece.

As all long pieces in a centre may be rendered secure against bending by cross braces or radial pieces notched on and bolted to them, this rule may, in nearly all cases, be applied for centres, instead of the rules in Chap. II.

In the centre, Fig. 2,* the beams EF, FF′, and F′E′, constitute the chief support; the arch is an ellipsis, and consequently a considerable part of it will bear almost wholly upon the centre. But from what has been shown respecting the pressure of the arch-stones, it will appear that if we take the whole weight of the ring between D and C, and consider it to act in the direction HF at the joining F, it will be the greatest strain that can possibly occur at that point from the weight of the arch-stones. Produce the line HF to *f*, and make *h f* to represent the pressure. Draw *h e*

* Atlas, Plate X.

parallel to the beam EF. Then, as hf represents the pressure of the arch between D and C, he will represent the pressure in the direction of the beam FE; and ef the pressure in the direction of the beam FF′; and these beams must be of such scantlings as would sustain these pressures.

Let the weight of the arch from H to H′ be estimated, and if two-thirds of this weight be considered to act at C in a vertical direction, it will be the greatest load that is likely to be laid at that point, and the dimensions for the parts of the truss FCF′ must be found so as to sustain that pressure.

The frame, EDF, may be calculated to resist half the pressure of the arch-stones between B and H.

The whole weight of the arch-stones from D to C, together with the weight of the centre itself, may be considered as acting in a vertical direction at E, and the supports at GE should be sufficient to sustain the action of this pressure.

To determine the scantlings of the ribs which support the weight between H and C, or D and H, &c., calculate the weight of that part of the arch which rests upon them, and consider it as a weight uniformly diffused over the length. The proper scantlings can then be found by the previous rules (91). These bearings may be much shortened by lengthening the blocks against which the inclined beams of the truss abut.

Section II.—Wooden Bridges.

117. Examples of Bridges.—The oldest wooden bridge of which we have any account is the Bridge of Sublicius, which existed at Rome in the reign of Ancus Marcius, about 500 years before the Christian era. The next in point of antiquity was that erected by

Julius Cæsar for the passage of his army across the Rhine. The bridge built by Trajan over the Danube appears also to have been of timber, except the piers, which were of stone. The roadway of this bridge appears to have been supported by three concentric curved ribs of timber, connected by radial pieces, and is certainly a good specimen of the art of building timber bridges at that early period. Trajan's bridge consisted of twenty or twenty-two stone piers, with wooden arches, each arch above 100 feet span.

In the middle ages, when bridges began to be established at the passages over the principal rivers, they were almost always constructed with piers, from 15 to 20 feet apart, consisting of one or more rows of piles. These piers were generally defended by a kind of jetta to break the ice, which also protected the piers from the shock of bodies borne down by the current; nevertheless, in process of time, and from the frequent repairs that were necessary to protect the piers, the water-way generally became almost wholly blocked up; and, consequently, the bridge soon became incapable of sustaining the pressure of water which accumulated in high floods.

The whole of the construction of these bridges was of that kind where abundance of material is made to supply the skill of the artist; yet there are cases where a similar but lighter kind of wooden bridge may be employed with much advantage; that is, in places not subject to floods, or for raising a road across a valley; and, generally, for any situation where the piers can be kept light.

A bridge that was built by Palladio over the Brenta, near Bassano, is a good example of this kind of bridge. (See Atlas, Plate XI., Fig. 3.) Also, the Bridge of St. Clair, on the Rhone, built by Morand. In the

latter bridge the piers were not constructed in the usual manner, but shorter piles were driven, and cut off a little below low-water mark. On the heads of these piles horizontal pieces were placed, so as to receive the posts to sustain the beams of the roadway, to which these horizontal pieces were secured with straps. As that part of the pier which is alternately wet and dry is subject to very rapid decay, this method renders it easy to repair it without disturbing the lower piles.

Palladio, in his "Treatise on Architecture," has given several designs for bridges, which display a considerable degree of knowledge of the subject; indeed, many of the designs of the present time are merely improvements of the principles exhibited in his valuable work. Palladio appears to have been the first among the moderns who attempted a species of construction that would render numerous piers unnecessary, and so as to avoid exposing any part of the timber-work to the shock of bodies carried down by the current. The bridge he erected over the torrent of Cismone, near Bassano, was of this kind, and the span 108 English feet. (See Plate XI., Fig. 1.)

Among the designs for wooden bridges given by Palladio, the most remarkable is that exhibited by Fig. 2; as it appears to have been the first idea of constructing a system of what may be termed framed *voussoirs*, similar to the arch-stones of a stone bridge; a principle that has since been adopted with much success both in timber and in iron bridges.

Of the modern methods of construction, the best appears to be that of forming curved ribs for the support of the road-way; and this principle seems to have been first applied to bridges by Mr. Price, in his "Treatise on Carpentry." Mr. Price's method may be

stated as follows: He proposes the curved rib to rise about one-sixth of the opening, and to divide it into a convenient number of equal parts, according to the span, or to suit the lengths of the timber. For a bridge of 36 feet span, he proposes to make the ribs of pieces of oak in 5 lengths, and 3 inches in thickness; each rib to consist of two thicknesses, one 12 inches deep, and the other 9 inches deep; the joints crossed, and the thicknesses keyed together with wooden keys. Two of these ribs with joists framed between, he says, will be sufficient to support the roadway.

The famous wooden arch of 250 feet span, across Portsmouth River, in North America,* is put together with wooden keys similar to those proposed by Mr. Price; indeed it is precisely his method of construction applied to a larger span, excepting a little difference in the form of the keys.

In Switzerland several excellent wooden bridges have been erected; one of the most celebrated was that of Schaffhausen, constructed in 1757. It was composed of two arches, the one 172 feet, the other 193 feet span, supported by abutments at the ends, and by a stone pier in the middle, which remained when the stone bridge was swept away in 1754. The construction is ingenious, and the principle is shown in Fig. 4, Plate XIII. (Atlas.)

The construction of bridges with stone ribs has been much improved by Wiebeking. Instead of forming the ribs of short lengths, he employs pieces of considerable length, and bends them to the form of the curve. This method has many advantages over that in which short pieces are used: it lessens the number of joints, consequently the ribs are more firm, and less liable to decay. The Bridge of Freysingen, on the

* See Atlas, Plate XI., Figs. 4, 5 6, 7, 8.

Isar, in Bavaria, is one that was constructed according to Wiebeking's method, in the years 1807 and 1808. It consisted of two arches of 153 feet span, with a rise of 11·6 feet; and the width of the roadway was 25 feet. See Plate XII., Figs. 1 and 2 (Atlas).

The ribs which supported the roadway consisted of two parts, the one more curved than the other; that which was most curved was built with three courses of beams, of from 12·6 to 14·5 inches in thickness, and about 46 feet in length; each beam having been bent to the proper curve by screws or levers, and scarfed and bolted to the rest. The upper part of the rib consisted of only two courses of beams of 15·5 inches each.

Each of the abutments was 21·25 feet in thickness, and rested on 68 piles. The piles were from 30 to 38 feet long, and 15·5 inches square; and they were driven from 17·4 to 19·4 feet into the ground, with a ram of 1,486 pounds weight. The straighter parts of the curved ribs abutted against 5 piles, which were driven within about three feet of the back of the abutment; these piles were 12·6 inches square, and had 20 feet hold of the ground, and were also further strengthened by building the abutment round them. In the elevation of the bridge, Fig. 94, the abutment to the left of the figure is supposed to be cut through, to show how the two parts of the rib abut into it.

Each arch consisted of three curved ribs, which were bonded together at seven places, by cross ties, each consisting of several pieces of timber laid one upon another: and these ties supported seven ranges of beams, laid in the direction of the length of the bridge, with diagonal braces between them, and the joisting of the roadway laid across them.

In the spaces between the springing of the arches

and the first cross tie, inclined braces were fixed crossing one another, and similar braces were fixed between the cross ties on each side of the crown of the arch, serving to strengthen the bridge against any lateral strain. The upper part of the ribs was continued into the abutments for the same purpose.

The pier, which sustained the arches in the middle, consisted of nine vertical piles of 17·5 inches diameter, driven about 17·5 feet into the bed of the river; and two inclined piles about 46 feet long. The base of the pier was surrounded by a bed of large gravel stones, with the joints filled with water cement. The ends of the ribs abutted into vertical posts, which rested upon horizontal sills, that were secured to the piles by bolts and straps. A lining of strong oak planking was placed between the vertical posts and the piles, and the spaces formed between the planking and the piles were filled with beton, or concrete. Fig. 3 is a section across the bridge close to the pier.

In order to preserve the timbers, the mortises and tenons of the vertical posts were soaked in hot oil; and small gutters were made near the lower ends of the curved ribs and braces to cause the water to run off, instead of settling into the joints. To all the principal timbers two coats of pitch and tar were applied.

The exterior of the bridge was covered with boarding, painted, and dark lines drawn for the joints, so as to imitate a stone bridge.

The Bridge of Bamberg, on the Regnitz, in Germany, is another example of Wiebeking's methods of construction; the widest span that has been executed according to his principle. It was built in 1809.

It consists of one arch of 208 feet span, with a rise of 16·9 feet, and the width of the roadway is 32 feet. (See Atlas, Plate XII., Figs. 3, 4.) A stone bridge

had formerly been erected on the same site; but its heavy piers contracted the waterway so much, that the water in a flood accumulated to such a height as to overturn the bridge by its pressure. In consequence of this accident the wooden bridge was made to span the whole width of the river.

In the middle of the width of the bridge, three ribs are placed side by side, the middle one being five beams in depth at the abutments, but only three in depth at the crown; but the ones on each side of it are three beams in depth throughout. On each side of the bridge there are two ribs placed side by side, and bolted together; these each consist of five beams in depth towards the abutment, and three beams in depth at the crown. The depth of the beams are from 13·5 to 15·5 inches. The three compound ribs are united together by cross ties, with diagonal stays or braces between, as in the Freysingen Bridge; also the roadway is constructed in the same manner.

In the elevation, Fig. 3, the boarding is supposed to be removed from one-half of the bridge, and the abutment cut through, to show the manner of framing the timbers. Fig. 4 is a section across the bridge at A A on the elevation, to a larger scale.

The joints of all the parts built into the abutments were well soaked in hot oil, and also covered with sheet lead. The ribs and joists are of fir, the cross ties and plates of oak.

118. The Design of Wooden Bridges.—The principal objects to be attended to in designing a bridge are, first, the choice of a proper situation; secondly, the width of the roadway; thirdly, the waterway which ought to be left for the river; and fourthly, the span of the arches. Each of these is chiefly determined by local circumstances.

The choice of situation depends much upon local circumstances, and should be that which is most convenient to the public, and so that the means of access are commodious. The bridge should always cross the stream as nearly as possible at right angles. A correct section of the river bed must be made, and the depth of water ascertained at different seasons of the year.

The width of roadway may be from 18 to 45 feet, where carriages have to pass over, and from 5 to 8 feet for foot-bridges.

The waterway must be sufficient to give free passage to the highest floods, which must regulate the height and width of the arches.

The extent of the span is in some degree determined by the quantity of waterway. The span of the arch, however, must also be regulated by the form of the banks, the height of the highest floods, the depth and rapidity of the river, and the kind and dimensions of the timber that can be procured.

In rivers which are tranquil, of little depth, and not subject to high and rapid floods, the number of piers may be augmented without inconvenience, provided they do not interrupt the navigation of the river, nor contract too much the waterway.

But if the bridge have to cross a torrent, the least possible number of supports should be placed in the stream. When the banks are not too low, and the width of the river does not exceed 300 feet, the engineer should give the preference to one arch. When more than one arch is required, much expense cannot be saved by making the span of the arches large, because the piers in such cases require to be carefully constructed, and there will be much additional labour, and consequently expense, both in the arches and piers. But if the opening be not greater

than can be spanned with one arch, it would certainly be the best method to do it so, especially if the banks be high on each side.

The rise of the arch or arches is generally limited by the form of the roadway and the height of the highest water-line, as that line should be the springing of the arch. The roadway should always be of as easy an ascent as circumstances will admit of; ascending from each side to the middle in a rise of about one part in 36, gives the bridge a slight curvature, which improves its appearance; but it ought not to rise at a quicker rate than one part in 12.

Wiebeking names a rise of one in 24 as that which may be used without inconvenience; but he observes that in timber bridges the settlement is generally about one part in 72; that is, if a timber bridge of 144 feet span rise one foot in the middle when first framed, it will settle so as to become nearly horizontal; therefore, when it is intended that the bridge shall have an ascent of one in 24 when finished, it must be framed so as to have a rise of one in 18.

But when the rise of an arch or truss is limited, whether it be by the form of the roadway or any other local circumstance, the span is also limited; for if the span does not bear a certain proportion to the rise, the bridge will not support its own weight. This proportion depends on the radius of curvature of the curve of equilibrium, and from the length of this radius we may also determine to what extent a single arch may be constructed. The largest span of which we have any correct account being executed with timber, is the bridge over the Limmat, near Wettingen; this span is 390 feet, the whole rise about 43 feet, and the radius of curvature of the curve of equilibrium about 600 feet.

It has been found by experiment that the force

required to crush a square inch of oak is 5,147 pounds; and suppose one-fifth of this force to be a sufficient load to trust upon each square inch in a bridge, this force would be equivalent to the weight of a column of the same material 2,950 feet high. And it is shown by writers on the strength of materials, that in an arch of the same material, of which the radius of curvature is equal to the height of this column, the parts of the arch will be pressed with the same force as the weight of the column.

Consequently, in a bridge constructed of oak, the radius of curvature should never exceed 2,950 feet; and for fir it should not exceed 3,000 feet.

But then the construction is similar to a framed lever; the abutments being secured by a horizontal tie, the radius of curvature of the curve of equilibrium of the compressed part of the frame, when it is sufficiently loaded with its own weight, will be only half the height of the column that would produce an equal pressure on the same base, because in this kind of construction there is at least double the weight of materials. Therefore, in a bridge with horizontal ties, the radius of curvature should not exceed for oak 1,475 feet, for fir 1,500 feet.

These numbers only give the radius when the frames, or ribs, are sufficiently loaded with their own weight; but there is the roadway and the timbers connected with it, which add nothing to the strength of the bridge. But the radius of curvature of a bridge which will be sufficiently loaded when the whole weight to be laid upon it is taken into consideration, may be found by the following proportion:—

As the whole weight of the bridge
Is to the weight of the supporting frame;
So is the radius of curvature above determined
To the radius required.

These calculations suppose the parts of the bridge to be accurately balanced, according to the principles of equilibrium; and it is obvious that any defect in this respect must render it necessary to increase the curvature.

Wiebeking gives some proportions for the rises for different spans, but not from principles; his proportions being founded entirely upon the observations he had made in practice. As far as regards appearance, he states one-tenth of the span to be the best proportion for the rise of an arch; but as it is in general desirable to keep bridges low, he gives the following proportions:—

From	100	to 150	feet span	make	the rise	$\frac{1}{20}$
"	"	200	"	"		$\frac{1}{18}$
"	"	300	"	"		$\frac{1}{16}$
"	"	400	"	"		$\frac{1}{14}$
"	"	500	"	"		$\frac{1}{13}$
"	"	600	"	"		$\frac{1}{12}$

119. Piers for Supporting Bridges may, in simple cases, be constructed by driving a single row of piles for each pier in a line with the current of the river. The piles may be from 10 to 14 inches square, and placed at from 2 to 4 feet distance from one another. The piles should be strengthened by oblique braces. Fig. 8, Plate XI., represents a pier of this kind.

In a deep river, or where the height of the roadway is much above the surface of the water, it is difficult to get piles of sufficient length. In such a case the piles may be driven and cut off a little below low-water mark, and upon these piles posts may be placed for supporting the roadway. The joinings should be secured by means of horizontal pieces well bolted together. A, B, and C, Fig. 1, Plate XV., show the way in which the upper and lower parts of the pier should be connected. The piers of the Bridge of St. Clair, at Lyons,

are constructed nearly in this manner, and it has the advantage of giving good hold to the piles, besides rendering them much easier to drive; it also cuts off the connection between the part of the pier which is constantly wet, and of long duration, and that which is alternately wet and dry; consequently, it is much easier to repair or renew the posts, which will, from their situation, often require it.

But when the depth of the river is very considerable, it would not be safe to trust to a single row of piles; in that case the lower part should consist of a double row of piles, BB (Fig. 2, Plate XV.), at about 3 feet distance from middle to middle, connected by the horizontal beams EE, and the cross pieces DD, for supporting the posts. In order to secure the feet of the posts, they must be clasped by two horizontal ties, C, C, and the whole well bolted together. Fig. 8, Plate XI., and Fig. 6, Plate XII., show how the posts may be braced; and when their height is considerable, one or more courses of horizontal ties will be required besides the inclined braces.

Instead of driving piles for the piers or supports of a wooden bridge, Telford adopted another method with perfect success on the river Severn, about eight miles below Shrewsbury. He made choice of any convenient situation on the banks of the river for constructing the pier, which consisted of an upright frame having a grated frame attached so as to form its base, the base extending on each side of the upright frame. The framing was then sunk in its proper situation, the bottom having been carefully levelled to receive it. Through the spaces in the grated frame short piles were driven to keep the whole secure in its place. The sides of the upright frame were covered with planking, and in order to add to the stability the lower parts were

filled with gravel and small stones. To prevent ice, or other bodies carried down by the current, from injuring the piers, the edges of the frames which face the stream may have triangular pieces of cast iron fixed upon them. Fender piles are also sometimes driven so as to form a triangle at a little distance above and opposite to each pier.

When a river is subject to ice floods, the piers should be protected by ice-breakers, which should be detached, in order that the bridge may not be injured by the shock of bodies descending by the current. The ice-breaker, A, B, Fig. 5, Plate XII., consists of a single row of piles, connected by two horizontal beams, with an inclined capping, the edge of which is protected by a triangular prism of cast iron.

Fig. 3, Plate XV., is a plan and side elevation of an ice-breaker, consisting of two rows of inclined piles, the heads of which abut against an inclined capping, protected with iron as before. The inclined sides to be covered with planking, which is not shown on the engraving.

120. Timber Frames for Bridges.—Before proceeding to specify the modes of construction adapted to particular cases, a few observations on the general principles of construction will perhaps render the advantages of the methods proposed more evident.

Let AB, Fig. 1, Plate XIII., be a solid beam resting upon the supports A and B. If we suppose this beam to be the support of a roadway, it will, besides its own weight, have to support the planking and road, as well as that of any heavy body moving over it.

A beam may be made stronger, with the same quantity of timber, by making it deeper in the middle, and less at the ends, as in Fig. 2; for a strain at C will have less effect in bending that beam, than one at the

middle of the length. And, however the weight may be distributed, if it be sufficiently great it will cause the beam to bend; and when a beam bends, it is observed that the fibres at the upper side *d* are compressed, and that those on the lower side *e* are extended. Also that there may be a line drawn at the middle of the depth *a c b*, where the fibres are neither extended nor compressed, but remain in their natural state. But all the fibres between *c* and *d* are compressed, and all those between *c* and *e* are stretched; though not equally so, because the nearer a fibre is to the points *d* or *e* the more it is strained. Now, as the middle part of the depth of the beam is very little strained, in comparison with the upper and lower sides, it is clear that we can employ the same quantity of timber in a more effectual manner, by using a deeper beam, cutting it down the middle, and framing the parts together, as is shown in Fig. 3; because we have seen that the middle part exerts very little force, and its weight is a considerable load on the beam.

If we now attend to the forces exerted by the parts of the beam, it will be found that the upper part, *a m d n b*, is wholly compressed in the direction of its length, and that the lower part, *a r e s b*, is wholly extended in the direction of its length; and it is well known that timber offers the greatest degree of resistance when strained in the direction of its length, provided the necessary degree of security can be given to the joints.

From these considerations we are naturally led to the kind of construction shown by Fig. 4, where it is obvious that the same pressures obtain as in the perforated beam above described; the only difference being, that here the tie beam is supported, as otherwise it would fail in large spans. The celebrated bridges of Schaff-

hausen, Zurich, Landsberg, and Wettingen are constructed on this principle. In the bridge of Schaffhausen the disposition of the timbers is nearly the same as is shown by Fig. 4. The continued tie AB retaining and being an abutment for the compressed beams, the frame requires only to be supported, and has no other thrust on the abutments of the bridge than a solid beam would have. Framed bridges, such as that designed by Palladio, Fig. 1, Plate XI., may be referred to the same principle.

It is easy to conceive that the tie might be entirely removed, provided the abutments were made capable of sustaining the thrust. This, without any other change, leads us to the kind of construction represented in Fig. 5, which has been adopted by Joseph Ritter for a bridge across the torrent of Kandel, in the canton of Berne.

But as long pieces of timber require to be of a proportionate depth and breadth, consequently are not easily procured, and in scarfing much of their strength is lost, a kind of construction where short timbers only can be procured is desirable. Fig. 6 represents a combination which may be used in such cases with advantage. Such combination has been often employed; we have an example in that of Palladio across the Brenta (see Plate XI., Fig. 3); and the Bridge of St. Clair, over the Rhone at Lyons, is of the same kind.

We cannot, however, derive much benefit from shortening the beams, by dividing the span into shorter lengths, because the angles of junction become more obtuse or open, and of course the strain in the direction of the pieces is much increased. And, however strong such a bridge might be, in respect to a constant load distributed over it, the weight of any load moving upon it would soon derange it; because the strength of such a system to resist a variable load must depend wholly

on the strength of the joinings, to which it is difficult to give much strength. Nevertheless, bridges have been both designed and executed on such principles, as is represented by Figs. 7 and 8. The combination, Fig. 7, resembles the Bridge of Mulatière, at Lyons, over the Saone; and Fig. 8 is combined nearly in the same manner as the arches of the bridge at Walton, which was found in a state of decay in twenty years. The Bridge of Sault, on the Rhone, was also on the same principle as Fig. 8, and failed within thirteen years.

From combinations of the kind last noticed, the continued curved rib naturally succeeds, which possesses advantages not to be found in a series of beams merely abutting end to end. For when the rib is built of short lengths with the joints crossed, and the different thicknesses firmly bolted together, it becomes as one solid beam. If we suppose the straining force to be applied at D, Fig. 9, then the force must be sufficient to fracture the rib at C, D, and E; therefore, when the strength of the rib is capable of sustaining the strains of C, D, and E, and the curve is a proper curve of equilibrium to the constant load, this is at once a simple and effectual combination. The use of curved ribs of this kind has been extensively employed in the construction of bridges, and it has been further improved by bending the pieces which form the ribs. A rib composed of bent beams is shown by Fig. 10.

As a bridge with a curved rib, when the span is considerable, yields at D, C, and E (Fig. 10) when the load is applied at the middle, the strength must of course be increased, by increasing the depth of the rib; and consequently a framed rib, such as is shown by Fig. 11, is the next step in the progress of improvement. Here, however, it must be observed that the

two curved ribs must be continuous, and put together so as to resist either extension or compression, as in Fig. 10. For when a load is placed at D, the lower rib will be extended at *d*, and compressed at C and E; while the upper one will be compressed at D, and extended at *c* and *e*. And a weight applied at any other point would produce a similar effect. When the span becomes so great that two curved ribs can be introduced without being made smaller than is required for the firm connection of the parts of each rib, then framed ribs would be a vast addition to the stability of the bridge.

In timber, however, where we have nothing to fear from expansion, it is losing one of the greatest advantages of the material to interrupt the connection of the parts; besides, numerous joints should always be avoided, both on account of the difficulty of making them fit, so as to bring every part alike into action, and the difficulty of preventing decay at such joinings.

In some instances it is difficult to form abutments, and also desirable to keep the roadway as low as possible; in such cases, Fig. 12 shows a kind of construction that may be used. It is peculiarly adapted to a situation where the banks of the river are low, and where there is no navigation to interrupt. Where the width of the bridge is considerable, a rib may rise in the middle of the width, so as to divide the roadway into two parts. Sometimes a double rib might be placed in the middle, with a footway between. But where there is much attention paid to architectural effect, bridges with framing to rise above the roadway will seldom be adopted. As cross ties will be necessary at the top, the middle parts might be covered with a roof to protect them; also a continued coping, *a a*, *á á*, might be put

over each truss, which would improve the appearance, as well as protect the framing.

When the distance of the abutments, or piers, does not exceed 16 feet, a bridge may be constructed by simply laying beams across the opening of about 15 inches deep, by 8 inches in breadth, and about 2 feet apart. For foot-bridges this kind of construction may be extended to 18 feet, with the same scantlings. When the extent of bearing for a bridge for carriages does not exceed 35 feet, the kind of bridge shown by Fig. 3, Plate XI. (Atlas), may be adopted. When there are more openings than one, any of these simple forms might be much strengthened by continuing the beams over more than one opening, when the timber is long enough ; and when it is not, by scarfing the beams together at the points of support. Also, short pieces of timber may be placed under each beam, extending from 5 to 7 feet on each side of the cap of the pier, as at AA, Fig. 3. The bridge of Bassano is here given as an example of this kind of construction. It was erected at a place where the river was 194 English feet wide, which was divided into five equal spaces by the piers. Each pier consisted of eight piles 30 feet in length and 18 inches square, placed 2 feet apart. The width of the bridge was 26 feet.

As it has been shown that curved ribs are preferable to other methods of spanning a wide opening, it will only be necessary to select two or three cases as examples. If the span is not more than 50 feet, each rib may be composed of two or three thicknesses of planks of a convenient length, bolted together, and the joints crossed ; one of three thicknesses is preferable. The ribs should rise as much as an attention to the form of the roadway and other circumstances will allow ; and they should be about from 6 to 9 feet

apart, with the roadway supported by upright pieces in pairs, notched and bolted to the ribs. As the weight of the roadway presses in a vertical direction, and it may be considered as a general principle, that each piece (when possible) should be placed in the same direction as the force that it is intended to sustain acts in; therefore the reason for placing them upright is evident. The distance of the upright pieces should never exceed 15 feet, and horizontal cross ties should be placed at the same points, with diagonal braces, to prevent the bridge from vibrating sideways when heavy loads are moving over it. Diagonal pieces should also be inserted between the road timbers, as lateral motion should as far as possible be prevented.

In spans exceeding 50 feet, there will be difficulty in obtaining timber deep enough for the ribs; therefore they should be built the contrary way, and bent to the required curve, so as to increase the depth. The beams forming the ribs should be scarfed at the joinings; the form of the scarf should be such as would resist either pressure or tension, and the scarfs should be kept as distant from one another as possible. The number of thicknesses in each rib must depend on the size required for the span, and the dimensions of the timber that can be procured; and the whole should be well bolted together.

Fig. 1, Plate XIV., represents a bridge designed for a 200 feet span: Fig. 2 is a section across at CD to a larger scale. This bridge is sustained by four ribs, each rib 18 inches thick and 4 feet deep; the ribs to be two thicknesses in width, and either 3 or 4 feet in depth, according to the size of the timber; the lengths of timber should be disposed so as to cross the joints as much as possible, and the joints should be scarfed. One of the most simple scarfs will be the best adapted for that purpose. The pieces composing a rib must be well

bolted together, and keys in the joints would be a further means of preventing any sliding of the parts.

The vertical pieces which support the roadway are intended to be put on in pairs, notched to the ribs, and bolted together, and not more than 18 feet apart. And at each pair a double tie is intended to cross both the back and the under side of the ribs, notched on to the ribs, and bolted to the vertical pieces.

Between the timbers which carry the joists of the roadway diagonal braces should be framed so as to secure the bridge from lateral motion. A series of braces for the same purpose might be framed over the back of the ribs; but one of these methods, if well executed, will be sufficient.

The bridge is intended for a gravel or paved roadway, and is calculated to sustain two loaded waggons at its weakest point without injury. This kind of bridge is adapted to any span that is usual in bridge building. The ribs should not be more than 8 feet apart. The curvature to be given to the beams will be sensibly uniform, and the degree of uniform curvature which may be given to a beam is inversely as its depth, or the radius of curvature will be *as* the depth. Wiebeking observed, that when several pieces of wood were placed one upon another, they would curve much more without fracture than a single piece would do. Wooden bridges, however well constructed, will always settle a little immediately after being built, and this settlement will increase in a small degree with time.

As the beams are intended to be bent to the form of the rib, it will be prudent to ascertain whether such a degree of curvature may be given to the beams without impairing their elastic force.

The degree to which a beam can be bent without destroying its elasticity is found as follows, R being the radius of curvature :—

For English oak	$\cdot 05 \times R =$	the depth of the beam in inches.
For Riga fir .	$\cdot 035 \times R =$	,, ,, ,,
For larch . .	$\cdot 077 \times R =$	,, ,, ,,

If the span be greater than 250 feet, instead of single curved ribs it would be an advantage to make frames, each consisting of two curved ribs, with radial pieces, and crosses between, as shown in Fig. 3, Plate XIV. The ribs should be formed in the manner above described. The radial pieces should be notched on to the ribs, in pairs, and bolted together; the diagonal pieces, or crosses, halved together in the middle, and made to abut end to end between the radial pieces. Fig. 4 shows a plan of the framing, and Fig. 5 a section across at the middle.

At AB, Fig. 3, horizontal ties are notched and bolted to the vertical supports, so as to brace them in both directions; and a series of diagonal braces might be applied upon the horizontal cross ties, which would be very effectual in stiffening the bridge against lateral motion. The braces shown by dotted lines in Fig. 5 need be applied only at four or five places in the whole length of the bridge. The roadway to be formed and supported as in the preceding examples.

TABLE OF THE LEAST RISE FOR DIFFERENT SPANS

Span in feet.	Least rise in feet.	Span in feet.	Least rise in feet.
30	0·5	180	11
40	0·8	200	12
50	1·4	220	14
60	2	240	17
70	2½	260	20
80	3	280	24
90	4	300	28
100	5	320	32
120	7	350	39
140	8	380	47
160	10	400	53

It must be remembered that a small rise should be avoided if possible, because it requires a much greater quantity of timber to make the bridge equally strong.

121. THE ROADWAYS of bridges are constructed in various ways; but the most usual one is to pave upon gravel; sometimes gravel only is used, and some prefer planking only.

The planking in small bridges is often laid immediately upon the principal beams, which in such cases are placed about 2 feet apart; but it is better in respect to durability to lay cross joistings for supporting the planking; these joists should be about 2 feet apart, and the planking laid upon them, which may be from 3 to 4 inches thick. The cross joints admit the air to circulate more freely round the principal timbers, and therefore render them more durable. Figs. 1 and 5, Plate XIV., show the latter of these modes of construction.

Where bridges are intended for wheel carriages, there should be a separate footpath, which may be paved with flag-stones. Footpaths are made from 2 feet to 6 feet wide, according to the number of the passengers. The carriage-way may be paved upon a bed of gravel of about 12 inches in depth; the paving to rise in a curve across the road. The gravel should contain a considerable portion of tempered clay, so as to bind it firmly together; but if there be too much clay, it will shrink and crack in drying. Belidore states that paved bridges are the most durable.*

If the roadway should be covered only with gravel or broken stone, it should be from 12 to 18 inches deep in the middle, and from 9 to 14 inches deep at the sides, according to the traffic over the bridge.

* Sciences des Ingénieurs, p. 364, edit. 1814.

Whether the roadway be paved or gravelled, means of conveying off the water should be provided.

As the moisture which passes the gravel or broken stone soon rots the planking, it is supposed to be better to lay an additional thickness of planking, and no gravel or paving. In that case the upper planking should lay across the bridge to prevent the feet of horses sliding. It would be easy to renew such a roadway; but we do not see any other advantage it possesses. The planking of the roadway might be protected very much by a coat of pitch, tar, sand, or asphalte.

Parapets or balustrades are made from 3·5 feet to 6 feet in height above the footpath; 4 feet is enough for protection. The railing is stayed by braces on the outside. Iron railing is sometimes used.

122. Scantlings of the Timbers.—The greatest load likely to rest upon a bridge at one time would be that produced by its being covered with people. It should be such that the crowded procession may move along in perfect safety; and it is easily proved that this is about the greatest load a bridge can possibly have to sustain, as well as that which creates the most appalling horror in the case of failure. Such a load is about 120 lbs. per foot, and, together with the weight of the framing and gravelled roadway, would be about 300 lbs. on a superficial foot, or 0·14 of a ton. And as this load may be supposed to be uniformly diffused over the bridge, half the load upon it will be expressed in tons by $0 \cdot 14\, w \times s$, where $s =$ half the span, and w is equal to the width of the bridge.

If the bridge be only planked without gravel, as a foot bridge, the greatest probable load will be expressed in tons by $0 \cdot 09\, w \times s$.

Now, as the load is sensibly uniform, the curve of

equilibrium will be a common parabola; and when the rib is of this form any uniform load would have no tendency to produce any derangement or other strain in the rib than that which is propagated in the direction of the curve. Therefore the first object must be to determine the size of the ribs, so that they may be capable of resisting this pressure without being more compressed than is consistent with the stability of the structure.

Riga timber suffers a compression in the direction of its length of about one fifteen hundredth part of its length under a load of 64 tons upon a square foot; and oak bears about the same load with the same degree of compression. Under such a pressure the curved rib of a bridge 200 feet in length would shorten rather more than 1·6 inches: and as it is a material that soon decays, this will not appear too low an estimate of its strength.

Rule for bridges that are gravelled.—Multiply the width of the bridge by the square of half the span, both in feet; and divide this product by the rise in feet multiplied by the number of ribs; the quotient, multiplied by the decimal 0·0011, will give the area of each rib in feet.

Rule for bridges where the roadway is only planked.—This rule is the same, except multiplying by the decimal 0·0007, instead of 0·0011.

Section III.—Joints, Scarfing, and Straps.

123. The Joints of Timber Frames, having to support whatever strains the pieces joined are exposed to, should be formed in such a manner that the bearing parts may have the greatest possible quantity of sur-

face; provided that surface be made of the best form for resisting the strains.

The effect of the shrinkage and expansion of timber should also be considered in the construction of joints. On account of the shrinkage of timber, dovetail joints should never be used in carpentry, as the smallest degree of shrinking allows the joint to draw out of its place; and, consequently, it loses all its effect in holding the parts in their proper situation. Dovetail joints can only be used with success when the shrinkage of the parts counteract each other; a case which seldom happens in carpentry, but is common in joinery and cabinet-making.

Joints should also be formed so that the contraction or expansion may not have a tendency to split any part of the framing. The force of contraction or expansion is capable of producing astonishing effects where the pieces are confined, and may sometimes be observed in framing which has been wedged too tightly together in improper directions.

Where the beams stand square with each other, and the strains are also square with the beams, and in the plane of the frame, the common mortise and tenon is the most perfect junction. A pin is generally put through both, in order to keep the pieces united, in opposition to any force which tends to part them. Every carpenter knows how to bore the hole for this pin, so that it shall draw the tenon tight into the mortise, and cause the shoulder to butt close, and make neat work; and he knows the risk of tearing out the bit of the tenon beyond the pin, if he draw it too much. We may just observe, that square holes and pins are much preferable to round ones for this purpose, bringing more of the wood into action, with less tendency to split it. The ship carpenters have an in-

genious method of making long wooden bolts, which do not pass completely through, take a very fast hold, though not nicely fitted to their holes, which they must not be, lest they should be crippled in driving. They call it *foxtail wedging*. They stick into the point of the bolt a very thin wedge of hard wood, so as to project a proper distance; when this reaches the bottom of the hole by driving the bolt, it splits the end of it, and squeezes it hard to the side. This may be practised with advantage in carpentry. If the ends of the mortise are widened inwards, and a thin wedge be put into the end of the tenon, it will have the same effect, and make the joint equal to a dovetail. But this risks the splitting the piece beyond the shoulder of the tenon, which would be unsightly. This may be avoided as follows:—Let the tenon T, Fig. 41, have two *very* thin wedges, *a* and *c*, stuck in near its angles, projecting equally; at a very small distance within these, put in two shorter ones, *b*, *d*, and more within these if necessary. In driving this tenon, the wedges *a* and *c* will take first, and split off a thin slice, which will easily bend without breaking. The wedges *b*, *d*, will act next, and have a similar effect, and the others in succession. The thickness of all the wedges taken together must be equal to the enlargement of the mortise toward the bottom.

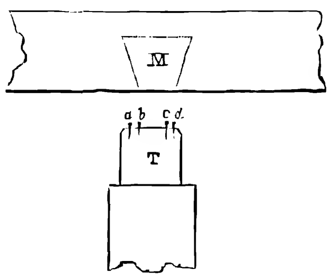


Fig. 41.

When the strain is transverse to the plane of the two beams, the principles laid down will direct the carpenter in placing his mortise. Thus the mortise in a

girder for receiving the tenon of a binding joist of a floor should be as near the upper side as possible, because the girder becomes concave on that side by the strain. But as this exposes the tenon of the binding joist to the risk of being torn off, we are obliged to mortise farther down. The form, Fig. 42, generally given to this joint is extremely judicious. The sloping part, *a b*, gives a very firm support to the additional bearing, *c d*, without much weakening of the girder. This form should be copied in every case where the strain has a similar direction.

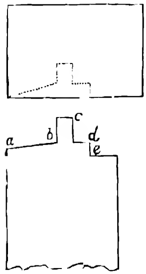


Fig. 42.

The joint that most of all demands the careful attention of the workman is that which connects the ends of beams, one of which pushes the other very obliquely, putting it into a state of extension. The most familiar instance of this is the foot of a rafter pressing on the tie-beam, and thereby *drawing* it away from the other wall. When the direction is very oblique (in which case the extending strain is the greatest), it is difficult to give the foot of the rafter such a hold of the tie-beam as to bring many of its fibres into the proper action. There would be little difficulty if we could allow the end of the tie-beam to project to a small distance beyond the foot of the rafter; but, indeed, the dimensions which are given to tie-beams, for other reasons, are always sufficient to give enough of abutment when judiciously employed. Unfortunately this joint is very liable to failure by the effects of the weather. It is much exposed, and frequently perishes by rot, or becomes so soft and friable that a very small force is sufficient, either for pulling the filaments out of the tie-beam, or

for crushing them together. We are therefore obliged to secure it with particular attention, and to avail ourselves of every circumstance of construction.

One is naturally disposed to give the rafter a deep hold by a long tenon; but it has been frequently observed in old roofs that such tenons break off. Frequently they are observed to tear up the wood that is above them, and push their way through the end of the tie-beam. This, in all probability, arises from the first sagging of the roof, by the compression of the rafters and of the head of the king-post. The head of the rafter descends, the angle with the tie-beam is diminished by the rafter revolving round its step in the tie-beam. By this motion the heel or inner angle of the rafter becomes a fulcrum to a very long and powerful lever much loaded. The tenon is the other arm, very short, and being still fresh, it is therefore very powerful. It therefore forces up the wood that is above it, tearing it out from between the cheeks of the mortise, and then pushes it along. Carpenters have therefore given up long

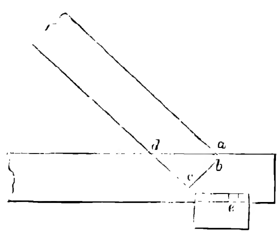


Fig. 43.

tenons, and give to the toe of the tenon a shape which abuts firmly, in the direction of the thrust, on the solid bottom of the mortise, which is well supported on the under side by the wall-plate. This form has the further advantage of having no tendency to tear up the end of the mortise. It is represented in Fig. 43. The tenon has a small portion, *a b*, cut perpendicular to the surface of the tie-beam, and the rest, *b c*, is perpendicular to the rafter.

But if the tenon is not sufficiently strong (and it is

not so strong as the rafter, which is thought not to be stronger than is necessary), it will be crushed, and then the rafter will slide out along the surface of the beam. It is therefore necessary to call in the assistance of the whole rafter. It is in this distribution of the strain among the various abutting parts that the varieties of joints and their merits chiefly consist. It would be endless to describe every nostrum, and we shall only mention a few that are most generally approved of.

The aim in Fig. 44 is to make the abutments exactly perpendicular to the thrusts. It does this very precisely; and the share which the tenon and the shoulder have of the whole may be what we please, by the portion of the beam that we notch down. If the wall-plate lie duly before the heel of the rafter, there is no risk of straining the tie across or breaking it, because the thrust is made direct to the point where the beam is supported. The action is the same as against the joggle on the head or foot of a king-post. We have no doubt but that this is a very effectual joint. It is not, however, much practised. It is said

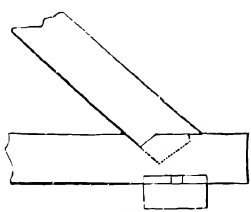


Fig. 44.

that the sloping seam at the shoulder lodges water; but the great reason seems to be a secret notion that it weakens the tie-beam. If we consider the direction in which it acts as a tie, we must acknowledge that this form takes the best method for bringing the whole of it into action.

Fig. 45 exhibits a form that is more general, but certainly worse. The part of the thrust that is not borne by the tenon acts obliquely on the joint of the

shoulder, and gives the whole a tendency to rise up and slide outward.

The shoulder-joint is sometimes formed like the dotted line *a b c d e f g* of Fig. 45. This is much more agreeable to the true principle, and would be a very perfect method, were it not that the intervals *b d* and *d f* are so short that the little wooden triangles *b c d*, *d e f*, will be easily pushed off their bases *b d*, *d f*.

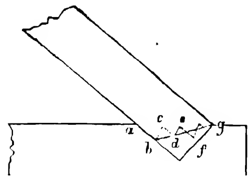


Fig. 45.

Fig. 46, No. 1, seems to have the most general approbation. It is the joint recommended in all books of carpentry as the *true joint* for a rafter foot. The visible shoulder-joint is flush with the upper surface of the tie-beam. The angle of the tenon at the tie nearly bisects the obtuse angle formed by the rafter and the beam, and is

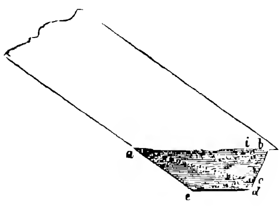


Fig. 46.—1.

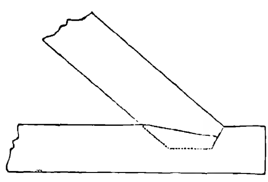


Fig. 46.—2.

therefore somewhat oblique to the thrust. The inner shoulder *a c* is nearly perpendicular to *b d*. The lower angle of the tenon is cut off horizontally, as at *e d*. Fig. 47 is a section of the beam and rafter foot, showing the different shoulders.

We do not perceive the peculiar merit of this joint. The effect of the three oblique abutments *a b*, *a c*, *e d*,

is undoubtedly to make the whole bear on the outer end of the mortise, and there is no other part of the tie-

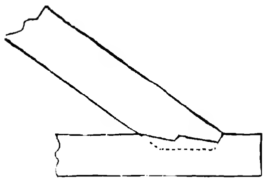


Fig. 46.—3.

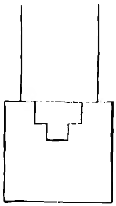


Fig. 47.

beam that makes immediate resistance. Its only advantage over a tenon extending in the direction of the thrust is, that it will not tear up the wood above it. Had the inner shoulder had the form *e c i*, having its face *i e* perpendicular, it would certainly have acted more powerfully in stretching many filaments of the tie-beam, and would have had a much less tendency to force out the end of the mortise. The little bit *c i* would have prevented the sliding upwards along *e c*. At any rate, the joint *a b* being flush with the beam, prevents any sensible abutment on the shoulder *a c*.

Fig. 46, No. 2, is a simpler, and a preferable joint. We observe it practised by the most eminent carpenters for all oblique thrusts ; but it surely employs less of the cohesion of the tie-beam than might be used without weakening it, at least when it is supported on the other side by the wall-plate.

Fig. 46, No. 3, is also much practised by the first carpenters.

Fig. 48 is proposed by Mr. Nicholson as preferable to Fig. 46, No. 3, because the abutment of the inner part is better supported. This is certainly the case ; but it supposes the whole rafter to go to the bottom of

the socket, and the beam to be thicker than the rafter. Some may think that this will weaken the beam too much, when it is no broader than the rafter is thick:

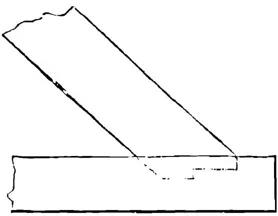


Fig. 48.—1.

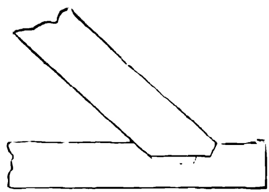


Fig. 48.—2.

in which case they think that it requires a deeper socket than Nicholson has given it. Perhaps the advantages of Nicholson's construction may be had by a joint like Fig. 48, No. 2.

Whatever is the form of these butting joints, great care should be taken that all parts bear alike, and the joiner will attend to the magnitude of the different surfaces. In the general compression, the greater surfaces will be less compressed, and the smaller will therefore change most. When all has settled, every part should be *equally* close. Because great logs are moved with difficulty, it is very troublesome to try the joint frequently to see how the parts fit; therefore we must expect less accuracy in the interior parts. This should make us prefer those joints whose efficacy depends chiefly on the visible joint.

It appears from all that we have said on this subject that a very small part of the cohesion of the tie-beam is sufficient for withstanding the horizontal thrust of a roof, even though very low pitched. If, therefore, no other use is made of the tie-beam, one much slenderer may be used, and blocks may be firmly fixed to the

ends, on which the rafters might abut, as they do on the joggles on the head and foot of a king-post. Although a tie-beam has commonly floors or ceilings to carry, and sometimes the work-shops and store-rooms of a theatre, and therefore requires a great scantling, yet there frequently occur in machines and engines very oblique stretchers, which have no other office, and are generally made of dimensions quite inadequate to their situation, often containing ten times the necessary quantity of timber. It is therefore of importance to ascertain the most perfect manner of executing such a joint. We have directed our attention to the principles that are really concerned in the effect. In all hazardous cases, the carpenter calls in the assistance of iron straps; and they are frequently necessary, even in roofs, notwithstanding this superabundant strength of the tie-beam. But this is generally owing to bad construction of the wooden joint, or to the failure of it by time. Straps will be considered in their place.

There needs but little to be said of the joints at a joggle worked out of solid timber; they are not nearly so difficult as the last. When the size of a log will allow the joggle to receive the whole breadth of the abutting brace, it ought certainly to be made with a square shoulder; or, which is still better, an arc of a circle, having the other end of the brace for its centre. Indeed, this in general will not sensibly differ from a straight line perpendicular to the brace. By this circular form, the

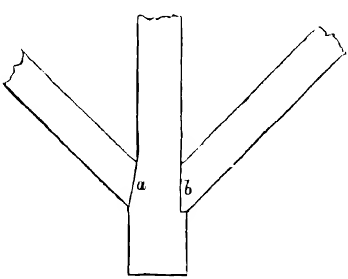


Fig. 49.

settling of the roof makes no change in the abutment; but when there is not sufficient stuff for this, we must avoid bevel joints at the shoulders, because these always tend to make the brace slide off. The brace in Fig. 49 must not be joined as at *a*, but as at *b*, or some equivalent manner.

When the very oblique action of one side of a frame of carpentry does not extend but compress the piece on which it abuts, there is no difficulty in the joint. Indeed a joining is unnecessary, and it is enough that the pieces abut on each other; and we have only to take care that the mutual pressure be equally drawn by all the parts, and that it do not produce lateral pressures, which may cause one of the pieces to slide on the butting joint. A very slight mortise and tenon is sufficient at the joggle of a king-post with a rafter or straining beam. It is best, in general, to make the butting plain, bisecting the angle formed by the sides, or else perpendicular to one of the pieces. In Fig. 50,

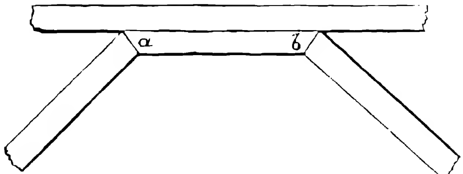


Fig. 50.

where the straining beam *a b* cannot slip away from the pressure, the joint *a* is preferable to *b*, or, indeed, to any uneven joint, which never fails to produce very unequal pressures on the different parts, by which some are crippled, others are splintered off, &c.*

124. Scarfing, or the mode of lengthening timber,

* For various modes of forming the joints of framing, see Atlas, Plates XVI. and XVII.

can be performed as represented in Fig. 51, Nos. 1 and 2. If considered merely as two pieces of wood joined, it is plain that, as a tie, it has but half the strength of an

1

2

3

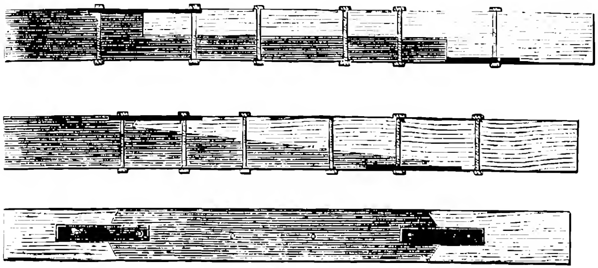


Fig. 51.

entire piece, supposing that the bolts (which are the only connections) are fast in their holes. No. 2 requires a bolt in the middle of the scarf to give it that strength; and, in every other part, is weaker on one side or the other.

But the bolts are very apt to bend by the violent strain, and require to be strengthened by uniting their ends by iron plates; in which case it is no longer a wooden tie. The form of No. 1 is better adapted to the office of a pillar than No. 2; especially if its ends be formed in the manner shown in the elevation No. 3. By the sally given to the ends, the scarf resists an effort to bend it in that direction. Besides, the form of No. 2 is unsuitable for a post; because the pieces, by sliding on each other by the pressure, are apt to splinter off the tongue which confines their extremity.

Figs. 52 and 53 exhibit the most approved form of a scarf, whether for a tie or for a post. The key represented in the middle is not essentially necessary; the two pieces might simply meet square there. This form, without a key, needs no bolts (although they strengthen

it greatly); but, if worked very true and close, and with square abutments, will hold together, and will resist bending in any direction. But the key is an ingenious and a very great improvement, and will force the parts together with perfect tightness. The same precaution must be observed that we mentioned on another occasion, not to produce a constant internal strain on the

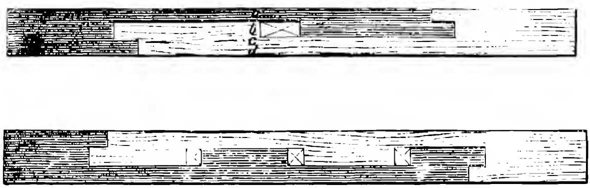


Fig. 52.

parts by over-driving the key. The form of Fig. 52 is by far the best; because the triangle of Fig. 53 is much easier splintered off by the strain, or by the key, than the square wood of Fig. 52. It is far preferable for a post, for the reason given when speaking of Fig. 51, Nos. 1 and 2. Both may be formed with a sally at the ends equal to the breadth of the key. In this shape

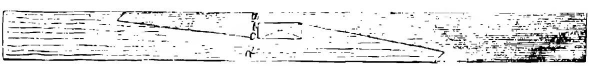


Fig. 53.

Fig. 52 is very well suited for joining the parts of the long corner posts of spires and other wooden towers. Fig. 52, No. 2, differs from No. 1 only by having three keys. The principle and the longitudinal strength are the same. The long scarf of No. 2, tightened by the three keys, enables it to resist a bending much better.

None of these scarfed tie-beams can have more than one-third of the strength of an entire piece, unless with

the assistance of iron plates; for if the key be made thinner than one-third, it has less than one-third of the fibres to pull by.

We are confident, therefore, that when the heads of the bolts are connected by plates, the simple form of Fig. 51, No. 1, is stronger than those more ingenious scarfings. It may be strengthened against lateral bendings by a little tongue, or by a sally; but it cannot have both.

The strongest of all methods of piecing a tie-beam

Fig. 54.

would be to set the parts end to end, and grasp them between other pieces on each side, as in Fig. 54. This is what the ship-carpenter calls *fishing* a beam; and is a frequent practice for occasional repairs. M. Perronet used it for the tie-beams or stretchers, by which he connected the opposite feet of a centre, which was yielding to its load, and had pushed aside one of the piers above 4 inches. Six of these not only withstood a strain of 1,800 tons, but, by wedging behind them, he brought the feet of the truss $2\frac{1}{2}$ inches nearer. The stretchers were 14 inches by 11, of sound oak, and could have withstood three times that strain. M. Perronet, fearing that the great length of the bolts employed to connect the beams of these stretchers would expose them to the risk of bending, scarfed the two side pieces into the middle piece. The scarfing was of the triangular kind, and only an inch deep, each face being two feet long, and the bolt passed through close to the angle. Various modes of scarfing are shown on Plates XV. and XVI. of the Atlas.

The following maxims will be sufficiently accurate for practical purposes:—

1. In oak, ash, or elm, the whole length of the scarf should be six times the depth or thickness of the beam, when there are no bolts.

2. In fir the whole length of the scarf should be about twelve times the thickness of the beam, when there are no bolts.

3. In oak, ash, or elm, the whole length of a scarf depending on bolts only should be about three times the breadth of the beam; and for fir beams it should be six times the breadth.

4. When both bolts and indents are combined, the whole length of the scarf for oak and hard woods may be twice the depth; and for fir, or soft woods, four times the depth.

Beams to resist cross strains require to be lengthened more frequently than any others; and from the nature of the strain, a different form must be adopted for the scarf from that which is best for a strain in the direction of the length. It would be a great advantage in such beams to apply hoops or straps of iron instead of bolts; and it would be easy to form the scarf so that the hoops might be driven on perfectly tight. There is no part of carpentry which requires greater correctness in workmanship than scarfing, as all the indents should bear equally, otherwise the greater part of the strength will be lost. Hence we see how very unfit some of the complicated forms shown in the old works on carpentry were for the purpose.

125. Straps.—When it is necessary to employ iron straps for strengthening a joint, considerable attention is necessary, that we may place them properly. The first thing to be determined is the direction of the strain. This is learned by the observations which have

been previously made. We must then resolve this strain into one parallel to each piece, and another perpendicular to it. Then the strap which is to be made fast to any of the pieces must be so fixed that it shall resist in the direction parallel to the piece. Frequently this cannot be done; but we must come as near to it as we can. In such cases we must suppose that the assemblage yields a little to the pressures which act on it. We must examine what change of shape a small yielding will produce. We must now see how this will affect the iron strap, which we have already supposed attached to the joint in some manner that we thought suitable. This settling will perhaps draw the pieces away from it, leaving it loose and unserviceable (this frequently happens to the plates which are put to secure the obtuse angles of butting timbers, when their bolts are at some distance from the angles, especially when these plates are laid on the inside of the angles); or it may cause it to compress the pieces harder than before; in which case it is answering our intention. But it may be producing cross strains, which may break them; or, it may be crippling them. We can hardly give any general rules; but the reader will do well to read what is said in the volume on Roofs. He will there see the nature of the strap or stirrup, by which the king-post carries the tie-beam. The strap that we observe most generally ill-placed is that which connects the foot of the rafter with the beam. It only binds down the rafter, but does not act against its horizontal thrust. It should be placed farther back on the beam, with a bolt through it, which will allow it to turn round. It should

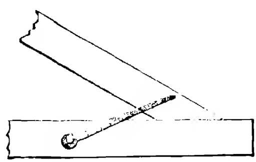


Fig. 55.

embrace the rafter almost horizontally near the foot, and should be notched square with the back of the rafter. Such a construction is represented in Fig. 55. The strap at the foot of a principal rafter is intended to form an abutment for it, in case the end of the tie-beam should fail; but if placed too upright it will become loose when the roof settles.

In Fig. 1, Plate XVII. of Atlas, *s* shows a strap for suspending the tie-beam to a king or queen-post: its hold of the post may be improved by turning the ends, as at *d d*, in the section E; these, when well fitted, with the addition of bolts, give the strap a firm hold; or staples, as in Fig. 2, may be used for a slight roof. The strengths of straps for different bearings are stated below. When the longest unsupported part of the tie-beam is

10 feet,	the strap	may be	1	inch	wide by	$\frac{3}{16}$	inch thick.
15	„	„	$1\frac{1}{2}$	„	„	$\frac{1}{4}$	„
20	„	„	2	„	„	$\frac{1}{4}$	„

These dimensions are quite sufficient for common purposes; but where the machinery of a theatre, or other heavy loads, are to be borne by the tie-beams, the straps must be made stronger in proportion to the load. In bolting on straps they ought to be drawn tight.

The use of straps at the feet of rafters is sometimes obviated by bedding the end of the tie-beam on the wall in a cast-iron SHOE, which serves the purpose of protecting the timber from the damp of the wall; and by having the back of the shoe as high as the depth of the tie-beam, all danger of the abutment to the rafter giving way is obviated, and it is only necessary to secure the foot of the rafter by a bolt passing through it and the tie-beam; this bolt should also pass through the under side of the shoe, so as to hold all three firmly together.

Section IV. — Scaffolding, Shoring, Coffer-dams, Bressummers, Story-posts.

126. A Gantry or gawntree is a staging or scaffolding formed of whole timber, erected around a building which is to be constructed or faced with hewn stone. This is framed with uprights or standards 10 or 15 feet apart, supporting longitudinal pieces or runners laid on the top of them, the bearing being strengthened by means of struts as shown on Fig. 50 (page 223). A capping of wood is placed between the top of each standard and the runner, to prevent it from injuring the latter; and the lower ends of the standards are either let several feet into the ground, down to a solid foundation, and firmly wedged in their places, or else tenoned into a horizontal sill laid along the ground. On the longitudinal pieces a rail is generally laid for a travelling windlass, or *traveller*, to move along, by which heavy stones can be lifted and carried to any part of the building. When the scaffolding is of very great height it is divided into stages by horizontal pieces, or transoms, and is strutted at each stage by making the ends of the transoms project beyond the outer standards. The uprights should also be strutted from the ground, in the manner of raking shores, in order to prevent them from being forced out of perpendicular, and to check vibration.

The scaffolding erected for the purpose of building the Nelson Monument at Charing Cross, London, was of the kind above described. The total height was 180 feet; and was divided into seven stages varying in height; the lowest stage being 48 feet high and the topmost one 21 feet. The uprights were tenoned a short distance into the transoms, which latter projected 6 feet beyond the outer uprights to support the flying wind-braces, by which the whole framework was

stiffened. In constructing these scaffoldings care is taken to cut and injure the timber as little as possible, so that when taken down it can be sawn up and used for building purposes with but little waste of material.

A large amount of framed scaffolding was erected around the New Houses of Parliament, and some very ingenious contrivances were adopted for carrying up the towers and larger pinnacles. Fig. 56 shows the scaffolding by means of which the stones were hoisted in their places for the four great pinnacles of the Victoria Tower.

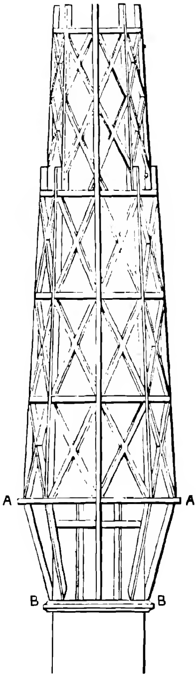


Fig. 56.

This frame-work or *cradling* was entirely independent of the masonry which was erected within it, and derived its support from a skeleton framed platform A A, whose timbers passed horizontally through apertures on each side of the octagonal pinnacle; these were bolted together and supported at each angle by raking-struts, A B, bearing upon the stone cornice below. On this platform the scaffolding was carried up in three stages, with eight uprights slightly inclined inwards, strengthened with cross-bracing and horizontal ties at each stage. The height of the stone-work from the cornice to the top of the pinnacle is 84 feet. A full account of the scaffolding used at the Houses of Parliament will be found in a paper read by Mr. Charles Barry at the Royal Institute of Architects, June 15, 1857.

TURNING-SCAFFOLDS are sometimes used for repairing or decorating the inside of domes or vaults. These are formed by attaching a platform to a pair of revolving masts, like the radii of a circle, which can be raised or lowered as required by means of ropes and pulleys; and can also be moved horizontally by the same means. The platform for the workmen is secured to the masts by means of hooks, so as always to be kept in a horizontal position.

A HOIST is a very simple kind of scaffold, in frequent use in some of the stone districts, and consists of a pair of masts placed a few feet apart, and braced together so as to form a skeleton frame. This is placed on a pair of grooved iron wheels, which run upon a horizontal bar laid on the ground parallel with the front of the building to be erected. On the top of this framework is a *jib* with a pulley, over which the chain or rope from the windlass below is passed. The hoist is secured by means of guide ropes, and is moved with great ease to any part where heavy stones have to be raised. When the stone has to be lowered upon the wall the guides are slackened, and the hoist allowed to lean forward so that the jib projects over the wall.

127. SHORING is a rough framing of timber erected against a wall for the purpose of securing it from falling. The mode of construction is as shown on Fig. 57; a plank, AB, is first fixed against the wall by means of the needles C, driven through it to the inside of the wall, the ends being left projecting out a short distance to receive the tops of the shores. *Raking shores*, D and E, are then fixed firmly on a template or footing, H, which is bedded on the ground, the tops of the shores being firmly wedged under the projecting ends of the needles C. When the wall is very high, a third shore, F, is fixed about halfway up the outer

shore E, the foot resting on a timber, G, which carries the pressure down to the footing. If the timbers are very long they are sometimes stiffened by the struts K. As the object of shoring is to convey the pressure from the wall down the axis of the timbers, and thereby down to the ground, the angle of inclination of the shores to the horizon should be as small as possible, or the footing H should be as far off the wall as circumstances will permit.

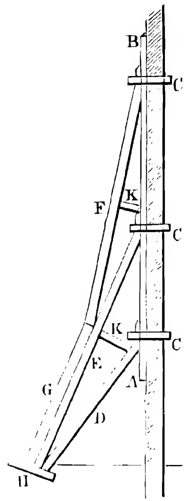


Fig. 57.

NEEDLING is another kind of shoring, and is used when a wall is perfectly upright, and when alterations have to be made in the lower story, such as the putting in a bressummer for a shop-front. Horizontal timbers, called *needles*, of large scantling, are driven at short intervals through the wall, the ends projecting 2 or 3 feet on each side; vertical shores are fixed under these, by which the whole weight of the wall above is carried down to the ground during the alterations.

STRUTTING with timber is used for various purposes in building. When the walls of two buildings lean towards each other on opposite sides of a narrow street, or if a deep excavation is being made in the road, struts of horizontal pieces of timber are placed across from wall to wall, the ends being let into vertical planks, or templates, placed against the wall; and, to prevent the shores from bending under the pressure, they may be stiffened by slanting struts abutting against the upper and lower parts of the templates, in the manner shown

on Fig. 50. A similar mode of strutting is employed when a deep and long excavation has to be made for a sewer or railway, to keep the earth from falling in, and save the necessity of sloping it back on each side.

128. COFFER-DAMS, being formed of timber, may be considered as part of the carpenter's business. They are watertight enclosures erected during the building of walls or piers whose foundations are under water, the water being pumped out of the coffer-dam before the building is commenced. They consist of rows of timbers, called *piles*, shod at the bottom with iron, which are driven down into the bed of the river as close together as possible, the interstices being filled in with clay-puddle. The piles in the first row are driven some feet apart, and serve as a *guide* to those of the inner rows, hence they are denominated *guide-piles*; inside these are fixed horizontal beams or *waling-pieces*, generally four in number, to keep the inner rows of piles from getting out of place. The inner and outer rows of piles are bolted together, and the space between them puddled with clay.

When it was required to build a river wall for the new Houses of Parliament at Westminster, a coffer-dam was constructed in the river Thames with piles 12 inches square and 36 feet long. The piles were driven 2 feet into the clay under the bed of the river, after a trench had first been formed by dredging in the line of the dam. The tops of the piles when driven rose 4 feet 6 inches above high water at spring-tides. To these were fixed waling-pieces and an outer row of sheet-piling, also formed of whole timber sawn perfectly square; these were driven close together and firmly bolted to the waling-pieces. An inner row of sheet piling formed of *half* timber was then driven, and on the top of these two rows of piles horizontal

pieces were securely fastened with bolts. Diagonal braces between the piling and the old river wall were introduced throughout the whole length of the dam, so as to resist the horizontal pressure of the water. The outer and inner rows were bolted together, and the space between them filled up with stiff clay. This dam was 920 feet in length.

For building the piers of London Bridge, coffer-dams elliptical on plan, were constructed. The main dam consisted of two rows of piles, leaving a space of 5 feet between each row, with the tops 5 feet above high spring-tides. These piles were connected by means of three rows of double walings secured with two-inch bolts and wooden cleats 12½ inches square and 3 feet long. A third and outer row of piles was also driven 6 feet beyond the second row, the heads of which were 7 feet below the others. These piles were connected by walings, as above described, and secured to the main dam by iron bolts and wooden cleats. The spaces between the rows were filled with clay, the exterior joints caulked and coated with pitch. All the above-named timbers were of *whole* timber. Sets of cross and diagonal braces formed of *half* timber were used to connect the rows of piles together; and the whole dam was braced longitudinally and transversely with double and single braces of *whole* timber, connected with iron straps and ties.

129. BRESSUMMERS are beams placed over wide openings to carry the wall above, as in shop-windows or openings for bay-windows. In shops, the ends of the bressummer usually rest upon two or more upright pieces of timber, called *story-posts*, which are tenoned into it, the lower ends of the posts resting upon stone bases or templates. To find the load that such a beam of fir will safely bear, when uniformly distributed over

its entire length, multiply the breadth by the square of the depth, and divide by the length of bearing; the result, multiplied by 2300, gives the safe load in lbs., all the dimensions being in inches. It is usual to saw the beam down the middle, reverse the ends, and bolt the pieces together, or else to use two *flitches*, and bolt them together. It may also be strengthened by a truss of iron placed between the flitches, or by a thin flitch of wrought iron. The strength of the *story-posts* depends much upon the height of the bressummer from the ground, the distance apart of the posts, and the load to be carried above; but, as a rule, the thickness should not be less than half the breadth, and the breadth is that of the bressummer to be supported.

LINTELS are pieces of wood laid across an opening for a door or window, to carry the wall above; they should rest at least 9 inches on the wall at either side, and the thickness varies from 3 to 6 inches, according to the span of the opening, the breadth being always equal to that of the wall above. When timber lintels are placed over wide openings they are denominated bressummers, as described above.

BOND timbers are pieces of wood sometimes laid longitudinally in brick walls for the purpose of *bonding* the work together; they are generally the thickness and breadth of a brick, namely, 4½ ins. by 3 ins., and if returned round two walls at right angles to each other are dovetail halved and spiked at the angles. As timber in this position is liable to rot, and thereby cause settlements in the wall after the lapse of several years, it is usual now to substitute iron hooping for timber bond.

* In order that the iron and timber may each exert its full strength, the thickness of the iron plate should be one-twentieth that of the timber.

129*a*. Story-Posts.—The following Tables of Scantlings are given by Tredgold for posts to carry stories of brick, built according to the regulations of the Metropolitan Building Act:—

Scantlings for Story-Posts, to carry Two Stories.

Height in feet.	4 feet apart.		5 feet apart.		6 feet apart.		7 feet apart.		8 feet apart.		Height in feet.
	Width.	Thickness.	Width.	Thickness.	Width.	Thickness.	Width.	Thickness.	Width.	Thickness.	
	inches.		inches.		inches.		inches.		inches.		
6	7½ ×	4½	7¾ ×	4¾	8¼ ×	5	8¾ ×	5¼	9¼ ×	5½	6
7	7¾	4¾	8¾	5¼	9¼	5½	9½	5¾	9½	5¾	7
8	8¼	5¼	9¼	5½	9½	5¾	10	6	10¼	6¼	8
9	9¼	5½	9½	5¾	10½	6¼	10¾	6½	10¾	6¾	9
10	9½	5¾	10½	6¼	10¾	6½	11¼	6¾	11¼	7	10
11	10½	6¼	10¾	6½	11½	6¾	11¾	7	12	7¼	11
12	10¾	6½	11¼	6¾	11¾	7	12½	7½	12¾	7¾	12
13	11¼	6¾	11¾	7	12½	7½	12¾	7¾	13¼	8	13
14	11¾	7	12	7¼	12¾	7¾	13¼	8	13¾	8¼	14
15	12	7¼	12½	7½	13¼	8	13¾	8¼	14¼	8½	15
16	12½	7½	12¾	7¾	13¾	8¼	14¼	8½	14½	8¾	16

Scantlings for Story-Posts, to carry Three Stories.

Height in feet.	4 feet apart.		5 feet apart.		6 feet apart.		7 feet apart.		8 feet apart.		Height in feet.
	Width.	Thickness.	Width.	Thickness.	Width.	Thickness.	Width.	Thickness.	Width.	Thickness.	
	inches.		inches.		inches.		inches.		inches.		
8	9½ ×	5¾	10 ×	6	10¾ ×	6½	11¼ ×	6¾	11¾ ×	7	8
9	10	6	10¾	6½	11¼	6¾	11¾	7	12	7¼	9
10	10¾	6½	11¼	6¾	12	7	12¼	7¼	12½	7¾	10
11	11¼	6¾	11¾	7	12½	7½	12¾	7¾	13¼	8	11
12	11¾	7	12½	7½	13	7¾	13¼	8	14	8¼	12
13	12	7¼	12¾	7¾	13¾	8¼	14	8½	14½	8¾	13
14	12¾	7¾	13¼	8	14¼	8½	14½	8¾	15	9	14
15	13¼	8	14¼	8½	14½	8¾	15	9	15¾	9¼	15
16	13¾	8¼	14½	8¾	15	9	15½	9¼	16¼	9¾	16

Scantlings for Story-Posts, to carry Four Stories.

Height in feet.	4 feet apart.		5 feet apart.		6 feet apart.		7 feet apart.		8 feet apart.		Height in feet.
	Width.	Thick-ness.	Width.	Thick-ness.	Width.	Thick-ness.	Width.	Thick-ness.	Width.	Thick-ness.	
	inches.		inches.		inches.		inches.		inches.		
8	10¼ ×	6¼	10¾ ×	6½	11½ ×	6¾	12 ×	7	12¼ ×	7¼	8
9	10¾	6½	11¾	7	12	7¼	12½	7½	12¾	7¾	9
10	11¾	6¾	12	7¼	12½	7¾	13¼	8	13¾	8¼	10
11	12	7¼	12½	7¾	13¼	8	14	8¼	14¼	8½	11
12	12½	7½	13¼	8	14¼	8½	14½	8¾	14½	8¾	12
13	13	7¾	14	8¼	14½	8¾	15	9	15¼	9¼	13
14	13½	8¼	14¼	8¾	15	9	16	9¼	16¼	9¾	14
15	14½	8¾	15	9	16	9½	16¼	9¾	16¾	10	15
16	15	9	15½	9½	16¼	9¾	16¾	10	17½	10½	16

Scantlings for Story-Posts, to carry Five Stories.

Height in feet.	4 feet apart.		5 feet apart.		6 feet apart.		7 feet apart.		8 feet apart.		Height in feet.
	Width.	Thick-ness.	Width.	Thick-ness.	Width.	Thick-ness.	Width.	Thick-ness.	Width.	Thick-ness.	
	inches.		inches.		inches.		inches.		inches.		
8	11¼ ×	6¾	11¾ ×	7	12¼ ×	7¼	12¾ ×	7¾	13¼ ×	8	8
9	11¾	7	12½	7½	12¾	7¾	13¼	8	14¼	8½	9
10	12¼	7½	13¼	8	13¾	8¼	14¼	8½	14½	8¾	10
11	12¾	7¾	13¾	8¼	14¼	8½	15	9	15½	9¼	11
12	13¾	8¼	14¼	8½	14½	8¾	16	9½	16½	9¾	12
13	14¼	8½	15	9	15½	9¼	16¼	9¾	16¾	10	13
14	14½	8¾	15½	9¼	16¼	9¾	16¾	10	17¼	10½	14
15	15	9	16	9½	16¾	10	17¼	10½	17¾	10¾	15
16	16	9½	16¾	10	17½	10½	17¾	10¾	18¼	11	16

TABLE OF THE PROPERTIES OF DIFFERENT KINDS OF TIMBER.

Kind of Wood, and state.	Specific Gravity.	Weight of the modulus of elasticity in lbs. per square inch.	Cohesive force in lbs. per square inch.	Comparative		
				Stiffness.	Strength.	Toughness.
Common English oak, dry	·750	1,714,500	11,880	100	100	100
Riga oak, dry	·688	1,610,496	12,888	93	108	125
Dantzic oak, seasoned	·755	1,998,000	12,780	117	107	99
American oak	·867	1,958,700	10,253	114	86	64
Beech, dry	·690	1,316,000	12,225	77	103	138
Alder, dry	·555	1,086,750	9,540	63	80	101
Plane, dry	·648	1,343,250	10,935	78	92	108
Sycamore, dry	·590	1,036,000	9,630	59	81	111
Chesnut, dry	·535	1,147,500	10,656	67	89	118
Ditto, green	·875	924,570	8,100	54	68	85
Ash, dry	·753	1,525,500	14,130	89	119	160
Elm, dry	·544	1,343,000	9,720	78	82	86
Acacia, green	·820	1,687,500	11,227	98	95	92
Spanish mahogany, dry	·853	1,255,500	7,560	73	67	61
Honduras ditto, dry	·560	1,593,000	11,475	93	96	99
Walnut, green	·920	837,000	8,775	49	74	111
Teak	·744	2,167,074	12,915	126	109	94
Poona, dry	·613	1,689,800	12,350	99	104	82
Turtosa or African teak, dry	·954	1,728,000	17,200	101	144	138
Poplar, dry	·374	763,000	5,928	44	50	57
Abele, dry	·511	1,134,000	10,260	66	86	112
Cedar of Libanus, dry	·486	486,000	7,420	28	62	106
Riga fir, dry	·480	1,687,500	9,540	98	80	64
Memel fir, dry	·544	1,957,750	9,540	114	80	56
Mar Forest fir	·684	845,056	7,323	49	61	76
Planted Scotch fir, dry	·460	951,750	7,110	55	60	65
Christiana white deal, dry	·512	1,804,000	12,346	104	104	104
American white spruce, dry	·465	1,244,000	10,296	72	86	102
Planted spruce, dry	·555	1,393,975	8,370	81	70	60
Weymouth pine, dry	·460	1,633,500	11,835	95	99	103
Pitch pine	·660	1,252,200	9,796	73	82	92
Larch, dry	·643	1,363,500	12,240	79	103	134
Cowrie	·579	1,982,400	10,960	116	92	74

In the last three columns of this table, English oak is made the standard of comparison.

AN ELEMENTARY TREATISE ON JOINERY.

BY E. WYNDHAM TARN, M.A.

Section I.—Technical Terms.

130. The Operations of Joinery require greater accuracy than those of Carpentry, since the work is nearer to the eye, and subject to closer inspection; the joints must be accurately fitted, and all the exposed surfaces rendered perfectly even and smooth. These operations consist of forming surfaces of various kinds, both plain and curved, grooving, rebating, tonguing, mitring, dovetailing, mortising, and tenoning; also the joining of pieces together so as to form a frame or solid piece of work; each of which operations will be described in the following pages. The wood used by joiners is called *stuff*, which must be carefully selected and free from all defects, such as sap, dead-knots, shakes, or cracks; and must also be thoroughly seasoned and dried, as described in Carpentry (7). This stuff consists of *planks* or *boards*, *deals*, and *battens*, so named according to their widths; battens vary from 2 inches to 7 inches in width, deals are 9 inches, and planks 11 inches; the thickness in the rough is 2½ and 3 inches. The stuff is sawn or ripped by the joiner to the thickness he requires; and if the width is insufficient, two or more boards of the same thickness are glued together at the edges.

The technical terms employed by joiners apply

equally to every part of their work; we shall therefore give an explanation of those terms before proceeding to describe the chief operations of Joinery.

131. GROOVING, or PLOUGHING, is the forming a rectangular channel, or *groove*, of uniform width in a piece of wood, as in Fig. 58, marked G; this is done in

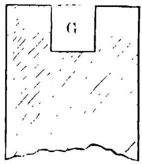


Fig. 58.

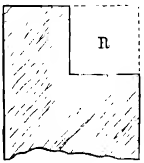


Fig. 59.

order to receive a *tongue*, or *tenon*, attached to another piece so as to fit the two together.

132. REBATING, or RABBETING, is the cutting a rectangular strip, called a *rebate*, or *rabbet*, out of one side of a piece of wood, as in Fig 59, marked R, to receive another piece, as in the hanging of doors or shutters.

133. MORTISING is the cutting a rectangular cavity, or *mortise*, within the surface of a piece of wood, in

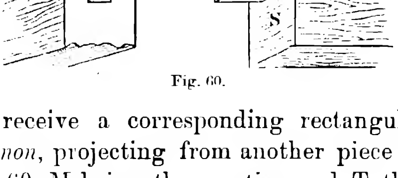


Fig. 60.

order to receive a corresponding rectangular piece, called a *tenon*, projecting from another piece of wood, as in Fig. 60, M being the mortise, and T the tenon; the solid pieces on each side of the mortise are called the *cheeks*, and the parts (S) from which the tenon pro-

jects are called the *shoulders*. Two pieces that are mortised together usually have the grain of one at right angles to that of the other. Mortises are also cut in the framework of doors to receive locks, &c.

134. TONGUEING is the insertion of a thin slip of wood or iron, called a *tongue*, into grooves previously cut or *ploughed* in two pieces of wood, for the purpose of keeping their faces in one continuous plane, as in Fig. 61, T being the tongue; when the tongue is cut across the grain of the wood, it is called a *feather-tongue*. The tongues are glued into their places, and the pieces forced close together with a cramp or by blows from a mallet.

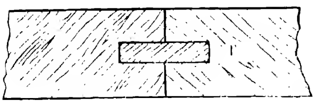


Fig. 61.

135. A MITRE is the diagonal joint which two pieces of wood make with each other when meeting at an angle, as M in Fig. 62. A *mitred border* is put round the hearths of fireplaces, to separate them from the wood floor.

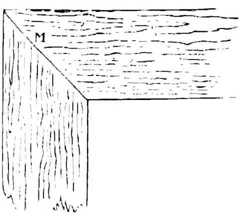


Fig. 62.

136. SHOOTING is the term applied to the making a straight edge to a board, which is then said to be *shot*. This is done to make two boards fit accurately together at their edges.

137. DOVETAILING is the joining two boards by indenting them together, the sections of the projection and hollows being in the form of a dovetail, as shown in Fig. 63.

Dovetailing is of three kinds — common, lap, and mitre; the *common* shows the form of the projections, and also of the excavations made to receive

them. *Lap* dovetailing conceals the dovetails, but shows the thickness of the lap in the return side, which appears like the edge of a thin board. Mitre dovetailing conceals the dovetails, and shows only a mitre on the edges of the planes at their surface of concourse; that is, the edges in the same plane, the seam or joint being in the concourse of the two faces, making the given angle with each other. This mode is used in fixing very wide boards together, where the seam or line of junction is in the concourse of the two faces, and the fibres of the wood of each board are perpendicular to a plane passing through such line.

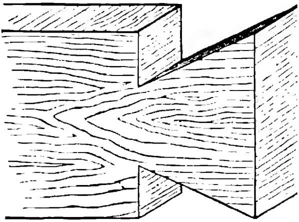


Fig. 63.

Concealed dovetailing is useful where the faces of the boards are intended to form a salient angle; but where they form a re-entrant angle, common dovetailing is best, as it is strongest and cheapest, and is entirely concealed, the dovetails only showing on the salient angle.

138. *Arris* is a term used to denote the sharp edge or external angle made by joining two pieces of wood the surfaces of which are not in the same plane. When the arris is cut off by a plane to a uniform width it is said to be *chamfered*.

139. Clamping is fastening several boards together to form one plane surface, by means of another board, or *clamp*, fixed transversely to the others at each end by means of mortise and tenon, or by a groove and tongue. If the clamp forms a mitre at each angle with the two outer boards, it is then said to be *mitre-clamped*.

140. Blockings are small pieces of wood fitted and glued to the interior angle of two boards, in order to strengthen the joint, as in the junction between the treads and risers of stairs.

141. Housing is the cutting a piece out of the face of one board for the insertion of the end of another, in order to fasten the two together, as in letting the ends of stairs into the strings.

142. Bracketing is a rough kind of framework, consisting of a number of small pieces of board an inch or more in thickness, placed at equal distances apart (about 12 inches) in the angles formed by the ceiling and walls of a room, so as to be partly on each, and at right angles thereto; to these pieces the laths for the cornice are nailed; the *angle-brackets* are placed so as to bisect the angles of the room, and must be made larger than the others in the proportion of the diagonal of a square to its side.

143. Angle-staffs are vertical slips of wood fixed to plugs driven into the exterior angles of the walls of rooms that have to be plastered, the outer faces of the angle-staffs being flush with that of the finished plaster; they are placed there to prevent the edge of the plaster from being broken. When the walls are intended to be covered with paper, the angle-staffs are square, or only slightly rounded at the outer edge; but when they are to be painted, the staffs are made with a quirked-bead on the outer edge.

144. Battening consists in fixing narrow slips of wood, called *battens*, to walls, for the purpose of nailing the plaster laths thereto, so as to keep them off the wall itself. This method is often adopted when the walls are liable to damp coming through from the outside. The battens are about 2 inches wide, and $\frac{3}{4}$ inch thick, placed about 12 inches apart, and nailed either to

plugs driven into the wall, or to bond timbers built in as the wall goes up; where they are fixed against flues iron holdfasts must be used to secure them to the wall.

145. MATCHED-BOARDING is a name given to a framing or partition formed of a number of boards exactly *matched* to an equal width, with a bead and tongue worked on one edge, and a groove on the other; the tongue of one board is then made to fit into the groove of the next, and the whole are secured together by ledges at the back. Matched-boarding is often used for the lining of walls, instead of plaster.

146. FEATHER-EDGED boards are those which are thicker at one edge than the other; they are used for covering the walls and roof of frame-houses (112), the thick edge of one board lapping over the thin edge of the one below; this is termed *weather-boarding.* They are also used for forming fences between fields, and are then fixed upright against horizontal rails. In common houses feather-edged boards are sometimes used for the treads of stairs, the thick edge forming the nosing (196).

147. FURRINGS are pieces of wood used for bringing up any piece of carpentry to a uniform level where it has become out of level by the bending or sagging of the timbers, or where there is an insufficient depth; as in the case of floor or ceiling-joists, which often have to be *furred* in order to make the floor boards perfectly level.

148. FILLETS are narrow slips of wood used for various purposes in joinery; thus *water-fillets* are fixed over the joints of ledged flaps or doors exposed to the weather, to prevent the rain getting in through the joints. *Tilting-fillets* are slips of wood nailed to the rafters of a roof, to lift or tilt up the slating where it abuts against a wall.

149. HEADING-JOINTS are the joints made by the meet-

ing of the ends of two or more boards or pieces of wood, and are at right angles to the direction of the fibres of the wood; they are usually ploughed and tongued.

150. VENEER is a thin layer of wood glued over a wooden backing, to give it a superior finish, or in order to form a curved surface; veneers are generally cut from expensive woods remarkable for the beauty of their grain and colour, such as Spanish mahogany, oak, satin-wood, walnut, rose-wood, &c. The panels of doors, hand-rails, and other parts of the joinery of a house, are often finished in this way.

151. HALVING is a method of joining two pieces of wood by cutting away each of them half its depth, and letting the remaining half of one into the part cut away in the other; the pieces are generally of the same thickness, and when they are halved together both the surfaces of each piece will be flush with one another. The width of the part cut away in one is equal to the width of the other piece, so that they exactly fit together.

152. PLUGS are pieces of wood inserted in a wall, and cut off flush with its face, to which wood linings are nailed.

153. SCRIBING is the cutting away of the edge of a board in order to make it fit exactly to a plane surface; this is usually done with the bottom edge of skirtings, which are *scribed* to the floor.

154. BEVILLING is joining two surfaces so as to make an oblique angle, or *bevil;* the term is also applied to cutting away the angle made by two surfaces. SPLAYING is a similar operation to bevilling, and is applied to cutting a board so as to make it thinner at one edge than the other, or fixing it so that it forms an obtuse angle with the piece that it joins, as the linings of a window, which are often fixed on the *splay*, or not square with the face of the wall.

155. WEDGES are pieces of wood wider at one end than the other, which are much used in tightening up the framework in all kinds of joinery, being driven into mortise holes in order to press the tenons closely to their places. They are generally dipped in glue before being driven. In order to make the tenon fix tight into the mortise, the end is sometimes split, and a projecting wedge inserted ; it is then driven into the mortise, the pressure against the bottom of which drives the wedge into the tenon, and expands it in width, so as to be firmly compressed against the sides of the mortise. This mode is called *foxtail-wedging.*

156. THROATING is cutting a groove underneath a projecting piece of wood, as a sill, or bottom rail of a casement or sash ; this is done to prevent water which might run down the face from returning under the bottom. Throatings are shown by the letter T in Fig. 64.

157. RAKING is a term applied to any piece of work fixed out of a horizontal or vertical line, such as the top-rail of spandrel-framing which fills up the triangular space under a staircase, or the mouldings of a pediment.

158. FRAMING is a term applied to the mortising together of a number of pieces (at least three) ; the mortises and tenons are first accurately fitted and then glued all at once, and wedged into their places by the help of a cramp ; this forms the skeleton framing, and the filling-in pieces are called *panels,* which are generally thinner than the framing, and are let into grooves cut in the frame before it is put together. When the framing has to be ornamented with mouldings, they are usually fixed afterwards, and mitred at the angles. When a surface is not all in one plane, or a straight edge does not touch it along its whole length in whatever direction it is placed, the surface is said to *wind;*

but when the straight-edge touches every part, however it is placed, the surface is all in one plane, and is said to be *out of winding*. When two pieces of a frame have their surfaces in the same plane, they are said to be *flush*.

Section II.—Floors and Skirtings.

159. Floors in joinery are boards which are laid close together upon the top of the joists previously fixed by the carpenter; they vary in thickness from half-an-inch to 3 inches, according to the requirements of the case; either battens, deals, or planks are used for flooring, but it is generally considered that the narrower the boards are the better is the floor, narrow battens being less likely to split, warp, or shrink than planks or deals. Deal floor-boards are cut out of 2½-inch or 3-inch stuff, and are often described according to the number of saw-cuts required to give the necessary thickness; thus, if 3-inch stuff is divided by one saw-cut down the middle of its thickness, the boards are called *one-cut* or 1½-inch; and if by two saw-cuts, they are termed *two-cut* or 1-inch, and so on. The actual thickness of the floor-boards when laid is about one-eighth of an inch less than that by which they are denominated, as they have to be planed on one side as well as sawn, both which processes occasion a slight loss of thickness. The floor-boards are fixed to the joists with nails called floor-brads, which in thin floors are driven straight through from the surface of the boards; but where the thickness of the boards is sufficient to allow it, they may be *edge-nailed*, or nailed at the edges in a slanting direction, so that no nail-heads appear on the surface. This, however, can only be done at one edge of the board. A *square* of flooring

is 100 superficial feet. There are several kinds of floors, which are named according to the mode adopted in laying the boards; as folding-floors, straight-joint floors, tongued-floors, dowelled-floors, and parquetry-floors.

160. FOLDING-FLOORS are laid by placing four boards together of equal length, which are shot as nearly as possible to fit a given space, and then forced downwards, folding into their places, as shown by Fig. 1.* These are the cheapest kind of floors.

161. STRAIGHT-JOINT FLOORS have the boards laid carefully the length of the room in regular straight joints, and then tightened together by means of a cramp (Fig. 2); † the ends of the boards, or *heading-joints*, are either splayed (Fig. 6),‡ ploughed, and tongued (Fig. 7), § or jointed, as Fig. 8, || taking care to break the joints at proper distances.

162. TONGUED-FLOORS have the longitudinal edges all ploughed and fastened with wood or iron tongues (Fig. 7); ¶ or else mortised and tenoned (Fig. 8),** a groove being ploughed on one edge and a tenon on the other, in which case they are nailed on one edge, the other edge being held down by the tongue, so that only half the quantity of nails is used of what is required for floors nailed from the top.

163. DOWELLED-FLOORS are laid straight and joined with wood or iron dowels, or pegs let into the edges of the boards to keep them down, instead of nails from the face (Figs. 3, 4, 5).†† If the boards are of oak, iron dowels are used; and with deal boards, dowels of beech or some hard wood. The dowels are 6 inches to 8 inches apart.

In first-class floors it is usual to lay a common deal

* See Atlas, Plate XXIII. † Ibid. ‡ Ibid. § Ibid. || Ibid. ¶ Ibid. ** Ibid. †† Ibid.

floor first, and the finishing floor on the top of it, but in the direction at right angles to the former.

164. PARQUETRY-FLOORS are those which are formed of variously coloured woods, such as oak, walnut, mahogany, and other hard woods; these are laid in geometrical patterns upon a common deal floor previously laid on the joists. There are two kinds of parquetry, veneered and solid; the former consists of veneers about one-eighth of an inch thick of the expensive woods glued upon a basis of deal or wainscot; and the latter is formed of solid wood about 1 inch in thickness, the pieces being glued and tongued together.

165. SKIRTINGS are the narrow boards fixed upright against a wall or partition round the margin of the floor, and forming a plinth for the base of the dado (see Plate XIX., Atlas), or simply a plinth for the room itself, where there is no dado above. When the skirting is placed close to the wall, it is nailed to a narrow horizontal slip of wood called a *skirting-ground*, which has been previously nailed to plugs let into the wall, so as to form a stop for the plaster. When the skirting stands forward from the face of the wall, it is sometimes let into a groove cut in the floor, as shown in Plate XIX. For large rooms requiring a deep skirting, it is made in two heights, the upper part setting back a little from the face of the lower part, and rebated into its top edge, so as to form a double plinth. The angles of skirtings are usually mitred and tongued.

If a skirting has no moulding on the top, it is called *square-skirting*; if the moulding is a quirked-bead, as shown on Plate XIX., it is termed a *torus-skirting*. Where other mouldings are used as cappings to the skirting, they are made separate from it, and fixed upon the top of the skirting, as the base of the dado in Plate XIX.

166. A Dado is a very deep skirting, the top of which is as high as the back of a chair, but the term is technically applied to the plane surface between the skirting and the surbase, or chair-rail, which goes round a room, as shown on Plate XIX.

The dado proper is made of deal boards, glued lengthwise edge to edge, with the heading joints ploughed and tongued, and the back keyed with keys tapered in their width and let into the back by a transverse groove. The mode of forming the dado is shown on Plate XXVIII.; by means of the narrow grounds K, tongues I, and keys G, the dado hangs unconfined, the joints being also secured by slips ploughed and glued into the back, as at H, and dovetailed pieces inserted at regular distances, as at M; the top and bottom of the dado not being confined, and the joints thus secured, there will be no danger of the joints opening, even should the deal shrink. The tongues I, through the grounds K, should be about 3 feet apart, as also the keys G, which must be about 3 inches wide at the bottom. B shows the common mode of rebating the dado into the grounds, but is not recommended. E is the fillet in the floor to secure the plinth, and F shows how it ought to be grooved into the floor. The internal angles of all dados should be grooved and tongued, and the external ones mitred. The dado is sometimes framed in panels.

The *base* of the dado is the moulding rebated on the top of the plinth. The *surbase*, or *chair-rail*, is the moulding on the top of the dado, and is fixed to grooved grounds attached to the wall behind (see Plate XIX.).

When a dado is fixed to a cylindrical surface, it has to be formed by bending and glueing several veneers of thin boards together; the first upon a mould or upon brackets, with their edges in the surface of the cylinder,

and parallel to its axis. This may be effected by having two sets of brackets fixed on a board, with a hollow cylindrical space between them, wide enough to take in the veneers, with double wedges for confining them; but as the wood has a tendency to unbend itself, the curved surface upon which it is glued should be rather quicker than that of the required cylinder. Another mode is to form a hollow cradle, and, bending the veneers into it, confine their ends with wedges, which compress them together; the glue is forced out of the joint by rubbing with a hammer. Boards of the required thickness may also be bent by cutting grooves at equal distances across, and bending them round a cradle with the grooves outwards, which are afterwards filled with slips of wood glued in; when the glue is dry these slips are planed down to the surface of the cylinder; the cylinder may be stiffened by glueing canvas at the back.

These methods of bending boards apply equally to all cylindrical surfaces, as the soffits of circular-headed windows or doors.

Dados are not much in use in modern buildings, but in old houses they are frequently found.

Section III.—Doors, Framing, and Shutters.

167. Doors are pieces of framework made to fit an opening in a wall, and hung so as to open and close at pleasure. The simplest form is the *ledged-door*, consisting of boards placed together upright, edge to edge, or with the edges tongued one into the other, and fastened together by transverse pieces of wood, called *ledges*, nailed to the boards; the edges of the upright boards are usually beaded or chamfered. Coach-house and church doors are generally made

after this fashion, but with the upright pieces at each edge thicker than the rest and framed into the ledges; diagonal bracing is used to strengthen the ledges. Ledged-doors are usually hung to the door-frames with *cross-garnet* hinges, which are in the form of a T, and are screwed on one side of the door and frame. Heavy doors, such as those used for coach-houses and churches, are hung with long iron bands, turning on a hook which is run with lead into a block of stone built into the wall.

168. DOOR-FRAMES consist of three, and sometimes four pieces of wood, framed together so as to leave an opening equal to that of the door to be hung thereto. They are usually fixed to the outer doors of a building, and consist of a lintel, about 18 inches longer than the clear opening, and two uprights, called side-posts, or *jambs*, tenoned into the lintel (see Fig. 1, Plate XXVII., Atlas); sometimes there is a wood sill at the bottom, into which the jambs are framed, or they are tenoned into the stone sill or floor boards. If there is to be a fanlight over the door, then a horizontal piece, called a *transom*, is framed into the jambs to cut off the space to be allowed for the fanlight, and forms the top of the door-opening. The door-frame is usually rebated about half an inch in depth to receive the door, and is also beaded all round; the width of the rebate is always equal to the thickness of the door.

169. FRAMED DOORS consist of vertical and horizontal pieces, mortised into each other so as to form rectangular openings, called *panels*, which are filled in with thinner stuff let into grooves cut in the edges of the framework. The horizontal pieces are called *rails*, and the vertical ones *stiles*; if there are three rails, the lowest is called the *bottom rail*, the middle one the *lock rail*, and the upper one the *top rail*; if there

are four rails, the highest but one is called the *frieze rail.* When the door is more than one panel in width, the uprights between the panels are called *muntings.* The mode of framing doors is shown on Plates XVIII. and XXVII. of the Atlas.

Doors are named according to the number of panels they are framed in, as one-panel, two-panel, four-panel, six-panel doors. When there are no mouldings planted round the panels, and the framing simply projects before them with a square edge or arris, the door is termed *square* (Fig. 3, Plate XXVII.); if a moulding is planted round the edge of the panel, it is called a *moulded* door (Fig. 5, Plate XXVII.); if the face of the panel is in the same plane on either side as that of the stiles and rails, it is called a *flush-panel* door; *bead-butt* when the flush panel has beads struck along two parallel edges (Fig. 4, Plate XXVII.); *bead-flush* when the beads are struck on the edges of the stiles and rails next the panels. When the edges of the stiles and rails are pared off round the panels, the framing is said to be *chamfered;* and if the *chamfer* stops short of the two ends, then it is said to be *stop-chamfered.*

When the moulding round the panels projects beyond the face of the stiles and rails it is called *bolection-moulded. Raised* panels are formed by making the middle of the panels thicker than the sides next the framing, and sloping them all round. (See Plate XXVI. Atlas.) The mouldings must always be bradded to the framing, and the brads must pass through the edges of the panels, otherwise the moulding will be drawn away from the framing when the panel shrinks, and spoil the appearance of the door.

170. FOLDING-DOORS are those which are hung in two or more leaves, or folds; if not intended to swing both ways, they are made with a rebate down the edge

of each outer stile, so as to form a lap when they meet, and a quirked-bead is planted on the opposite side of each door to that on which the rebate is cut.

Folding-doors that are made to swing both ways have no rebate, but are slightly rounded at both the outer edges of the stiles. (See Plates XX. and XXI Atlas.)

171. Door-linings. — The doors for rooms are usually hung to rebated *linings*, consisting of two jambs framed into a soffit, which are fixed to the openings in the wall or partition. The doors are hung with *butt-hinges* screwed to the rebate of the linings and also to the edge of the door, the knuckle of the hinges projecting before the face of the door; a piece of wood, the size and thickness of one-half the hinge, is cut out of the jamb and the edge of the door, and the hinge let into the sinking.

172. Swing-doors.—Where doors are required to swing both ways, as in public buildings, shops, &c., the linings are slightly hollowed, and the edges of the doors rounded; the doors are hung with pivots, or *centres*, let into the top and bottom of the door, the bottom centre being connected with a powerful spring sunk in the floor.

173. Sash-doors are those which have the upper panels rebated to receive a sheet of glass instead of a wooden panel. When much light is required to pass through the upper panels, they are made wider than the lower ones by reducing or *diminishing* the width of the stiles; the joints which the stiles make with the lock rail are then cut on a slant instead of being vertical.

174. Sliding-doors are those which, instead of being hung upon hinges, are made to run upon metal wheels, fixed either at the top or bottom of the doors, and running upon iron rails.

175. PANELS are slabs of wood let into grooves in the stiles and rails of framed doors, and are generally thinner than the framing. In common doors they should not be made wider than can be got out of the width of the wood without joining it; this is 11 inches in deal, which is as wide as a panel ought to be made, otherwise the door becomes weakened by not having enough stiles and rails, and is liable to wind in consequence.

176. LOCKS for doors are of various kinds; but there are only two ways of fixing them, either by screwing them on the outside of the lock rail, or by letting them into a mortise cut therein. The former plan is used for common doors, especially if there is not thickness enough to allow of a mortise being cut; the latter mode is used for doors not less than 2 inches thick, and where a superior class of finish is required. The knobs by which the bolt of the lock is shot backwards and forwards, called the *furniture*, are fitted on a spindle which passes through a hole drilled in the door; except in the case of draw-back locks, usually fixed on outer doors.

Escutcheons are plates or thin rims of metal fixed round the key-holes cut in the sides of doors.

177. FRAMING is the term applied to all kinds of joinery that are made up in panels with stiles and rails, doors being one particular branch of framing. Framed partitions are sometimes used to separate rooms, and are made with larger and thicker panels than are usual in doors.

Spandril-framing is that which incloses any triangular space, such as that between a flight of stairs and the floor below, or wherever there is a raking top rail, in which case the heads of the top panels are cut to the rake of the top rail. The linings to window backs and elbows are generally framed in panels; and some-

times the linings of doors are panelled, where the wall is of sufficient thickness to allow it.

178. SHUTTERS to windows are generally framed in the same way as doors. *Folding-shutters* are those which are hung in two or more widths, or folds, to the hanging stile, or back of the sash-frame, on each side of the window, the part that is hung to the stile being called the *shutter*, and the folding part which is hung to it the *back-flap*, the edge of each being rebated to receive that of the other. Fig. 8, Plate XXVII. (Atlas), shows the mode of hanging shutters to the sash-frame; and, when open, they are concealed in a *box*, and are, therefore, called *boxing-shutters*. The part marked L is the *boxing*, which is splayed, to allow the shutter to fall more easily into the box. H is the back lining, which may be plain or panelled, as shown in the figure. E is the principal shutter, and forms the side or jamb of the window-opening when the shutters are open; this is hung to the window-frame with butt hinges. F and G are the *back-flaps*, hung to the shutter with back-flap hinges, each edge being rebated. In this example the shutter and back-flaps are supposed to be framed in the usual way, with panels moulded on one side and bead-butt on the other. There will be a corresponding set on the opposite side of the window, and, when closed, they are fastened by an iron bar, generally hung by a pivot to one of the back-flaps, and swinging across two or more of the divisions. In order to keep the shutters close into the box, the outer edge of the front shutter has sometimes a spring catch, which locks into the edge of the boxing, L. Where the thickness of the wall does not admit of carrying out the above plan, the boxings must be projected forward as much as is necessary from the face of the wall, or else the shutters made to fall back upon the

wall itself, the shutter being hung to a narrow piece having a quarter-round edge or *rule-joint* and fitting behind the ground of the architrave. Plates XXIX. and XXXI. (Atlas) show the mode of hanging folding-shutters to a bay-window; as, however, they seldom fit well in such a case, sliding or lifting-shutters with balance weights are to be preferred, and these we shall proceed to describe.

179. Lifting-shutters are those which are hung with cords, pulleys, and balance-weights, and slide up and down in a groove or pulley-stile, behind which is the balance-weight passing over a pulley in the top of the pulley-stile and attached to the edge of the shutter. These shutters are usually hung in two heights, and slide one behind the other, being secured, when closed, by a thumbscrew passing through both. When the shutters are opened, they slide down below the window-sill and behind the framed window back, the top of the shutters being then concealed by a flap, which falls down and covers up the opening; rings are let into the top of each shutter for drawing it up when required to be closed. Similar shutters are frequently hung on the outside of shop windows, and slide down behind a framed casing.

180. Movable Shutters are those which are commonly used to the outside of shops, and are framed in several parts, each rebated at the edge to receive the others. They are fixed by sliding them in a horizontal groove at top and bottom of the window (Plate XXII. Atlas), and secured together by iron bars, going the whole length of the window, and iron screw-bolts let through at each end to the inside.

181. Revolving-shutters are those that are made to coil upon a roller either at the top, or bottom, or on the side of thewindow, the roller being placed out of

sight, and concealed by a lining, which is made movable for access to the machinery. They are formed of strong laths about $2\frac{1}{2}$ inches wide, made of wood or iron, which are fixed together by hinges, so that they can be easily wound over a roller, which is turned by a worm and wheel gearing, or else by a chain winding round it. For windows which are circular on plan these shutters are wound horizontally, the roller being placed vertically at one side of the window. These shutters work up and down in metal grooves fixed on each side of the window, and they can be used either on the outside or the inside of the window. In preparing for coiling-shutters it is necessary to fix the lintel a sufficient height above the clear opening of the window, to allow space for the laths to coil on the roller, the amount of which depends upon the height of the window. Shutters with laths of wood require a clear space for coiling of 9 inches in windows 5 to 7 feet high, of 11 inches for those from 7 to 10 feet high, and 13 inches for windows from 10 to 12 feet in height. When the laths are of iron the space required is 2 or 3 inches less.

In preparing for coiling-shutters, provision must be made for the easy removal of all linings that enclose any part of the machinery, so as to allow of access thereto for oiling, cleaning, and repairs, which are frequently required.

182. Gates are pieces of framing hung to the openings in fences or divisions between different properties, or at the entrance to private grounds. The width of a gate depends upon the use made of the roadway or path which it crosses. If it is only for foot-passengers or riding-horses, the width will be from 3 to 5 feet; but if for carriages or other vehicles, the width should not be less than 8 feet. The height

depends upon the requirements of the place ; but ought never to be less than 4 or 5 feet. Gates are framed of timber in various ways ; the simplest consisting of four pieces, framed in the form of a square or rectangle, with top and bottom rail and two stiles, or uprights, to which may be added a fifth piece, or brace, placed diagonally across to stiffen the framing and prevent it from getting out of shape. A sixth piece, or second brace, is also sometimes placed across the first, and halved upon it. The openings between the piece forming this frame are filled with upright or horizontal bars, or else the whole is close boarded ; the edges of the framing are sometimes stop-chamfered, and the stiles are carried above the top rail and rounded or ornamented.

In ornamental gates the lower half is sometimes framed in panels like a door, and filled in with narrow battens, chamfered at the edges and tongued ; the upper part may be left open, with cross bracing or open panels. Gates for wide openings are generally made in two leaves, one hung to each gate-post and meeting in the middle, with a rebated edge, as the folding-doors of a house. They are often framed up in panels, as in house-doors, as shown by Plate XXVI. (Atlas). Gates are usually hung with long iron bands, bolted on one side of the top and bottom rail, and turning on crooks let into the piers. (See Ironmongery, 204.)

Field-gates consist simply of a rectangular frame, with a diagonal brace and several horizontal bars nailed across the frame.

183. Lock-gates for canals, docks, or rivers, are very strong framings of timber, made to fold one against the other, the meeting edge being rounded off, and the back covered with stout boards tongued together. These gates are usually curved on plan, so as to resist the pressure of the water, and, when closed,

they fit tightly against a curved sill; they are opened and closed by help of machinery.

Section IV.—Windows.

184. Sashes are the wooden frames which hold the glass by which the openings of windows are filled. They are of various kinds and forms, some being fixed immovably in the opening, as in shop windows; others are hung with hinges like doors, and are called casements, or French windows; and another kind are made to slide up and down in grooves, with balance-weights to keep them from falling when open, and to assist in opening and closing them.

185. Sash-frames are the wooden frames which are fixed into the openings in the wall, and in which the glazed sashes are fitted; these are either made solid, and rebated to receive the sashes, or else they are *cased* of thin stuff in the form of a long box, with beads on each side to keep the sashes in their places.

186. Fixed Sashes consist merely of top and bottom rail and two side pieces, or stiles, framed together with mortise and tenon, and if the space is too large for one square of glass, it is divided by sash-bars tenoned into each other and into the stiles and rails; all the mouldings to the sash and bars are mitred at the angles. In small windows the sash is moulded on the inside all round, and rebated on the outside to receive the glass, which is puttied into it. In shop windows, however, the moulding is on the outside of the sash, and the rebate on the inside, the glass being secured by movable beads screwed into the sash-bar at the back of each square (Fig. 69). Frequently these sash-bars are made of thin brass laid over a core of wood.

187. Casements are sashes that are hung with butt-hinges to the sash-frame, as in the manner of

doors, in which case the frame is usually made of solid wood, and rebated the depth of the sash. Casements are made to open either inwards or outwards, the latter method being the best adapted to keep out the weather, especially in exposed situations. To render those which open inwards weather-proof, the stiles are grooved and a small projecting fillet is fixed on the side of the frame, which fits into the groove in the sash when it is closed; sometimes india-rubber tubing is used for this purpose, and, by making a tight joint between the sash and frame, it serves to keep out wind as well as rain. As it is generally at the junction of the sash with the sill of the frame that the weather drives in, the bottom rail of the casement should have a projecting piece of wood, or weather-board, to throw off the rain which runs down the glass. A method of making a weather-proof joint between the bottom rail of a casement opening inwards and the sill is shown on Fig. 64; T, T, T, being throatings. A hollow is made on the inner part of the sill to receive any water that may drive in, and this is carried off by means of holes drilled through to the bottom of the sill. In making casements great care is needed to have the wood well shrunk and seasoned, and the joints all accurately fitted. When casements are made to fold in two leaves, and to open inwards, those of a superior kind are fastened with an *espagnolette-bolt*, going from top to bottom of the sashes, and hooking the two firmly together at top and bottom. There is also another mode by means of a metal tongue, shooting backwards and forwards the whole height of the casement, which also serves to keep out weather.

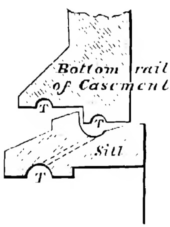


Fig. 64.

188. HUNG SASHES are those which are mostly used in private houses in this country, and have many advantages over casements, especially in being weather-tight, and allowing of being opened, in either a small or great degree, at top or bottom, so that the ventilation of a room can be better effected than with casements. Sashes of this kind are always placed in cased frames, the sashes being in two sheets, called top and bottom sash, and hung so as to pass one another in sliding up or down. The frame is made like a long box, with a front, back, and two sides, forming the soffit and the two jambs, the bottom being a solid sill, generally of oak, resting upon the stone sill of the window, and weathered outwards. The face of each jamb, towards the opening, is formed into grooves, called *pulley-pieces*, the exact width of the sash, divided by a *parting-slip*, to keep the sashes from touching each other, and prevent them from getting out of place when open. The sides of the case project in front of the pulley-pieces so as to form two grooves for the sashes to run in. The outer side of the case is called *outside-lining;* the side next the room, the *inside-lining;* that next the wall is the *back-lining.* A plan of this case is shown at Fig. 8, Plate XXVII. (Atlas), where *i, i,* are the inside and outside linings; see also Plates XXIV., XXV., and XXX. The pulley-pieces should be tongued into the linings, and the back-lining into the outside-lining, and nailed to the edge of the inside-lining; a groove is cut all round the frame, on the inside, for fixing the internal finishings. A long piece is cut out near the bottom of each pulley-stile to admit the balance-weights after the frame is fixed; this is filled in with a piece of wood, called a *pocket-piece*, which can be easily removed when the sash-line happens to break. Brass axle-pullies are fixed at the top of the pulley-stiles, and

over these the sash-line is passed, and attached at one end to the weight, which hangs down behind the pulley-piece, and by the other end to edge of the sash, in which a groove is cut to receive it. When the sash is *double-hung*, that is, both sheets are made to slide, there should be a parting-slip between the weights, to prevent them from catching against each other as they move up or down. When only one sheet or sash is hung, the window is said to be *single-hung*. Iron weights are generally employed in hanging sashes; but if very heavy, and the space small, lead, having a greater specific gravity, is used instead (Plate XXX). The bottom rail of the lower sash rests on the top of the oak sill, which is sloped or weathered outwards, the bottom rail being bevilled to fit the weathering. (See Atlas, Fig. 9, Plate XXVII., and Plate XXIV.) On the top of the sill and inside of the sash is a bead tongued to the sill, which keeps the weather from driving under; the sill is double-sunk, the edge of the top sinking being hollowed to prevent weather from driving up; there should be also a slight groove, or throating, cut in the under side of the bottom rail of the sash. Hung sashes, when closed, are fastened by a catch at the meeting rails, or by a thumbscrew passing through the meeting rails.

There is another mode of hanging sliding-sashes in cases where there is no room for balance-weights; namely, by making one sheet or sash balance the other, so that when the lower sash is pushed up the upper one descends, and *vice-versâ*. The sashes, in this case, are hung with lines in the usual way; but the same cord passes round both the pulleys, and under a third pulley concealed in the case, and is attached at each end to one of the sashes.

A *window-bottom*, or *capping-bead*, is tongued into

the inside of the sill, and a soffit into the head of the frame; the jamb-linings, or the back-linings, of the boxings for the shutters, if any, are tongued into the inside-linings of the frame, and the shutter itself is hung thereto.

189. Swing-sashes. — There is another mode of opening sashes, which is employed in certain kinds of windows; namely, by swinging them upon centres, or pivots, fixed on the middle of each side of the sash, and turning in plates let into the frame. The upper part of the sash falls inwards, when open, and the lower part is pushed outwards; the inside lining of the frame is cut across, at a slant, about the middle of the sash, the lower part serving as a stop to the sash when closed, and the upper part opening with it. It is usual

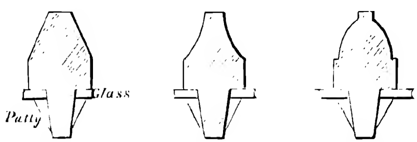


Fig. 65. Fig. 66. Fig. 67.

to open and close such sashes by means of a cord passing over a pulley fixed on the top of the frame. Sometimes the centres are fixed at top and bottom of the sash, which then opens vertically.

190. Sash-bars are moulded in various forms, such as the simple *chamfer* (Fig. 65), the *hollow* (Fig. 66), the *ovolo* (Fig. 67), the *lamb's tongue*, or *double-ogee* (Fig. 68), and the *astragal* and *hollow*, which has a quirked bead in front and a hollow on each side (Fig. 69).

191. Venetian-frames are those in which the opening of the window is divided into three parts by vertical pieces, called mullions; the side divisions are usually about half the width of the middle one. If the sashes are hung sliding, it is common to fix the sashes

in the side lights, and only hang the middle one, carrying the lines over two axle-pulleys, and letting the weights hang in the part of the frame next the wall; the mullions are then made solid with a lining on each side and parting-slip in the middle. If it is required to hang the sashes in all three lights, then the mullions must be cased, and made wide enough to receive the weights.

192. SKYLIGHTS are sashes placed over openings in the roof, and are commonly constructed in one plane following the slope of the roof, and sometimes made to slide up and down in grooves, or to lift up on hinges. Other kinds of skylights are of a pyramidal, conical, spherical, or ellipsoidal form, and elevated above the roof. A *curb* is fixed to the rafters, or joists, round the opening, and on this the skylight itself is fixed. For circular or elliptical openings the curb is in two thicknesses.

193. FANLIGHTS are sashes placed above an outside door, being let into a rebate cut in the door-frame and transom; they are usually fixed, but are sometimes made to open on centres.

SECTION V.—Mouldings, Columns, Staircases.

194. MOULDINGS are curved surfaces employed for the purpose of ornamenting various parts of the joiner's work, and are generally made by means of a moulding plane; but in some cases they are cut out by hand. *Architraves* are mouldings usually placed against the face of a wall round the openings for doors or windows, and are mitred at the angles. A flat piece of wood, called a *ground*, is generally first fixed to the wall, and rebated to the lining round the opening (as at C, Plate XVIII., Atlas). This ground is fixed before the plastering is

done, which is floated up to it, and the face of the work finished in the same plane with that of the ground. The architrave moulding is nailed on the face of the ground, so that part of it shall conceal the joint between the ground and the plaster (D, Plate XVIII., and M, Fig. 10, Plate XXVII.) Sometimes the architrave is worked out independently of the ground, which it entirely covers, as shown at C, Figs. 3, 4, and 5 (Plate XXVII., Atlas), and at M, Fig. 8; but in that case the plane portions are usually separate pieces from the moulding, and are made in two thicknesses (or more) for large doors, the outer edge of each thickness being moulded (Plate XXXIV.)

Mouldings are used to form the base and surbase of dados (Plate XIX.), and are also fixed on the top of skirtings where there is no dado. They are planted round the panels of doors and other framing, as before described, and, in fact, wherever a superior kind of finish is required in joinery. Cornices over shop windows or inside doors are constructed of wooden mouldings, each member of which is worked separately, and the whole glued, nailed, or screwed together, as shown on Plates XXI. and XXII. (Atlas).

There is a large variety of mouldings used in joinery; but these are, for the most part, made up of a few simple forms. The simplest form of moulding is the *rounding* of a projecting edge, so as to make a half-circle for its section; if this is made more than half a circle, it forms a *quirked-bead,* or torus (A, Plate XIX.) The *ovolo* (Fig. 67), page 262, is a segment of a circle, or ellipse, with a fillet at each end of the curve, as shown by the section of the pilaster A, B, Plate XXI. The *ogee* (Fig. 68) is a curve of contrary flexure, and is usually struck by two arcs of circles meeting at the line joining their centres; but a better form would be obtained

by using mathematical curves of contrary flexure (see Tarn's "Practical Geometry"). The top member of the cornice (Plate XXII.) is an ogee.

An *astragal* (Fig. 69) is a moulding having nearly a complete circle for its section, or a bead quirked on both sides. *Reeding* is sinking two or more vertical beads adjoining each other upon a plane or curved face, the beads being semi-circles on section sunk below the surface, and appearing like an assemblage of reeds (Fig. 70). *Flutings* are the reverse of reedings, being hollow channels cut side by side in a plane or curved face, the section of each being a semi-circle or other curve, and generally meeting in a narrow fillet

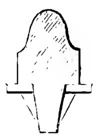


Fig. 68.

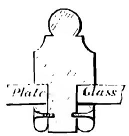
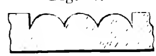


Fig. 69.

Fig. 70.



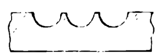


Fig. 71.

(Fig. 71). Reedings and flutings are often worked on the surface of columns and pilasters.

A *Cavetto* is a hollow formed with any curve for its section, the circle or ellipse being most commonly used.

The most complicated mouldings are usually made by combining some, or all, of the varieties above described, each moulding being got out of a separate piece of wood. For the best modes of drawing the contours of mouldings, the reader is referred to Tarn's "Practical Geometry."

Mouldings which have to go round a curved surface must be got out by hand, in short lengths to suit the required curve, and the joints should be dowelled

together with iron or hard wood to keep them from becoming distorted.

Raking-mouldings are those of which the arrises are inclined to the horizontal at any given angle, as the mouldings of a pediment. When a horizontal moulding has to be continued as a raking moulding, its section will be the projection of the horizontal one on a plane perpendicular to the line of the rake; all circular mouldings of the horizontal will be elliptical on the rake.

195. WOOD CORNICES, such as are placed over shop windows, are usually formed of several pieces in the manner shown on Plate XXII. (Atlas). The frieze is of narrow battens, keyed at the back in the same way as a dado, above described (164), and the joints are feather-tongued; this is fixed against a cradling of upright pieces of timber, or quartering, bracketed out from the bressummer, or from the wall above it; the mouldings of the cornice are fixed to the upper part of the frieze, which is carried up as high as the top member.

196. COLUMNS are sometimes framed of wood for ornamental purposes. When the diameter is considerable, they are usually made hollow, the real work of supporting the superstructure being done by an iron or timber pillar in the axis of the column, about which it is fixed. The mode in which such columns are constructed is shown by Plates XXXII. and XXXIII. (Atlas); in which a number of long staves are glued up together to form the contour of the shaft; sixteen staves are prepared in the above example, and a circle is drawn having the diameter of each end of the shaft, on which is circumscribed and inscribed polygons of 16 equal sides, those of the inner polygon being parallel to those of the outer one; the distance between the polygons must be equal to the thickness of the staves;

lines drawn from the centre of the circle to each angle of the outer polygon will give the mitres of the staves where they are to be united. Two staves, having been cut as marked out, are then glued together, and blockings glued at the back to strengthen them; then a third stave is joined and blocked at the back, and so on all round the column. When there is a core in the middle to support the superstructure, the column must be glued up in two halves, which are dowelled together, and the joints filled with white lead; they are then forced together by means of a rope round each end, tightened by twisting with a lever. If the column is to be fluted, the joints of the staves should be in the fillets between the flutings rather than in the hollows. The mouldings to the base and cap are constructed of thin slabs of wood in four or more pieces, glued together with blockings as above described, each moulding being got out of a separate slab. (See Plate XXXIII.) The abacus of a capital, such as the Corinthian, is glued up in parts with vertical joints, and the ornaments fixed thereto.

197. PILASTERS are formed with the front and sides of separate pieces mitred and tongued together at the angles, with blocks glued at the back down each angle; the front is sometimes framed into panels, as shown on Fig. 3 (Plate XXVIII.)

198. STAIRCASE is the term applied to the whole set of steps or stairs by which persons are enabled to ascend or descend from story to story in a building. When the story is of considerable height, it is usual to divide the stairs into two flights by forming a resting-place halfway up; this is called a *quarter-space* when a quadrant of a circle has to be turned from one flight to the other, and a *half-space* when a semi-circle has to be described. Staircases have several varieties of

structure, dependent chiefly on the arrangement and use of the building in which they are placed. *Geometrical* stairs are those which are supported by one end being fixed to the wall, and every step having an additional support from that immediately below it, the lowest step being supported by the floor.

Bracket stairs are those that have an opening or well, with strings and newels, and are supported by landings and carriages, the brackets mitring to the end of each riser, and fixed to the string-board, which is moulded below like an architrave.

Dog-legged stairs are those that have no well-hole, the rail and balusters of both flights falling in the same vertical plane, the steps being fixed to strings, newels, and carriages; in common stairs the ends of the steps terminate upon the side of the string without any housing.

In many of the old Elizabethan mansions the staircases are made in three flights at right angles to each other on three sides of the well-hole. Handsomely carved newels, of great size, are placed at each turn or angle of the staircase, and the handrail is framed into the newels. Examples of these staircases will be found in Richardson's "Old English Mansions."

The several portions of a wooden staircase are the steps, the strings, the carriages, the newels, the handrail, and the ballusters.

The *steps* consist of the *treads*, which are horizontal, and receive the foot of the passenger, and the *risers*, which are the upright pieces supporting the front of the treads. The proportion between the height and width of the step varies according to circumstances. The width of the tread should never be less than 9 inches, from 9 to 12 inches being the usual limit; the height from tread to tread ought never to exceed 7½

inches; but the greater the width of the tread, the less should be the height of the riser, and a tread of 12 inches ought not to be more than 6 inches above the lower one. The length of the steps ought never to be less than 3 feet, so as to allow of furniture being carried conveniently from floor to floor. The front edge of each tread is usually made to hang over the face of the riser, and to have a rounded edge or *nosing*, under which there is generally a moulding planted (Plate XXXV., Atlas). The riser is tongued into the under side of the tread above, and let into a groove in the tread below; blockings are glued inside the angle made by the tread and riser. The steps of a flight of stairs which continue of the same width and are all parallel to each other are called *flyers;* those which turn round a solid newel or circular well-hole are called *winders*, the treads being narrower at one end than the other. The bottom step of a flight is often finished with a scroll end called a *curtail* (H, Plate XXXV.); the riser of this scroll is made by bending a veneer round a solid block and wedging it to the straight part of the riser. The thickness of treads ought never to be less than 1¼ inch, and that of the risers 1 inch.

Strings are raking-boards placed at each end of the flyers, and by which the whole flight of steps is supported. The *wall-string* is that which holds the ends of the steps next the wall; the steps are sometimes housed into the wall-string and bracketed underneath, but often the string is cut away to receive each tread and riser, the ends of which completely cover it. The wall-string is nailed to plugs or grounds fitted to the wall, the bottom end resting on the floor joists. The *outer-string* is the board which supports the outer ends of the flyers, and rests at the lower end on the floor below,

the upper end being framed into the *newel* in the case of a dog-legged staircase, or the *pitching-piece* of the landing above in a well staircase. In common stairs the ends of the steps are housed into the string, but in the better kind it is usual to cut away the string for each tread and riser, mitring the string to receive the edge of the riser, and returning the nosing of the tread round the outside of the string; carved brackets are usually placed under the returned ends of the nosings (B, Plate XXXV.)

String-boards round circular openings are glued up in thicknesses, with the fibres following the line of the steps; sometimes they are glued up in vertical slips, as in the mode adopted for wooden columns (136). Strings are never less than 1¼ inch in thickness, and in common stairs would be cut out of an 11-inch plank.

Carriages are pieces of timber placed underneath the treads and risers of the flyers, to strengthen them and prevent them from bending under the weight of passengers (C, Plate XXXV.); the winders have framed and blocked carriages, the plan of which is shown at F, and G, (Plate XXXV.) The top ends of the carriages are framed into a horizontal piece of wood called an *apron-piece* or *pitching-piece*, which goes across from wall to wall; the *apron-lining* is the thin slab of wrought wood which covers the pitching-piece.

The *newel* is the post round which the steps turn in dog-legged staircases, and into which the outer string is framed; the ends of the winders are also framed into the newel. The lower part of the newel is generally made square, and finished with a carved pendant, and the upper part turned and ornamented.

The *newel-cap* is a moulded piece of wood, circular or polygonal on plan, into which the handrail is mitred,

the moulding of the cap corresponding in section with that of the handrail. In the old mansions the newels were often handsomely carved and surmounted with figures.

199. THE HANDRAIL of a staircase is a bar following the pitch of the stairs, placed so as to protect the outer edge of the stairs, and of sufficient height therefrom to assist persons in ascending or descending from one story to another. Handrails should be made of a size and section best suited to be grasped by the hand, as their name implies; those for dog-legged stairs, having no winders, are made straight from end to end, and housed into the newel at top, the lower end being bent upwards so as either to mitre it into a newel-cap or attach it to a scroll-end. In ancient mansions the handrail is always straight and framed into the newels at each end. It is usual in common staircases to form a bend called a *ramp* in the upper end of the handrail when it has to mitre into a newel-cap, giving it a kind of ogee form, but without turning it round to the right or left. In well-hole stairs the handrail is usually made continuous, and the portion which goes round the end of the well is called a *writhe*, being a curve of double-curvature, formed by wrapping a line in a spiral direction round a cylinder. The accurate formation of handrails to well-stairs is one of the most delicate parts of the joiner's business, and is generally executed by skilled workmen specially trained to the work, as moulds have to be prepared upon geometrical principles in order to make the writhes fit accurately in their places. The methods usually adopted are founded on the well-known mathematical principles, that the section of a cylinder cut obliquely by a plane is an ellipse, that the section parallel to the axis is a rectangle, and the section parallel to the base is a circle. If a hollow cylinder is cut by an oblique plane, the section obtained

will be bounded by two concentric and similar ellipses, and will be greatest in breadth at each extremity of the greater axis, and least at that of the lesser axis, so that in every quadrant there will be a continued increase of breadth from the extremity of the lesser to that of the greater axis. Let the height of the handrail at any three points of the writhe be marked on the cylinder, whose internal diameter is that of the well, and thickness that of the handrail, and a plane passed through those points, then the section will be a figure equal and similar to the face-mould of the required rail. Also by cutting the cylinder by a plane parallel to the first, and at a distance equal to the depth of the rail, the portion of the cylinder thus cut out will represent the rail itself with its vertical surfaces already wrought; and if the back and lower surfaces of this are squared to vertical lines on either side through two parallel lines drawn by a thin piece of wood bent upon that side, the moulds for the handrail will be completed. The first business of the handrail worker is to find the moulds for cutting a rail out of a flat piece of wood.

The *face-mould*, or *racking-mould*, is that which is applied to the faces of the plank so as to be vertical when the plank is placed in its natural position. The *falling-mould* is a parallel one bent to the side of the rail-piece for drawing the back and lower surface. The upper surface of the rail is called the *back*. The several parts of a handrail are joined with square heading joints fastened together with *handrail-screws* let into the end of each piece. The bottom end of a handrail is often finished with a scroll called a *curtail*, the moulds for which are made by drawing an outer and inner spiral, the space between them being the breadth of the rail. For methods of describing suitable

spirals for curtails the reader is referred to Tarn's "Practical Geometry." See also Collings on Handrailing.

In some cases handrails are got out in an inferior wood and then veneered over with ornamental woods; a superior appearance is thus obtained, and no heading joint appears on the rail.

200. BALLUSTERS are slender upright posts which support the handrail of a staircase, and are housed into the top of the treads or the edge of the outer string; they are of various designs, plain square, octagonal, or chamfered, turned with mouldings, twisted or otherwise ornamented. In old Elizabethan mansions the ballusters were very solid and elaborately carved.

Section VI.—Ironmongery.

201. IRONMONGERY is the name given to the various iron and brass fittings which are used by the joiner in the execution of his work. Under this title are included all the varieties of nails, screws, bolts, pulleys, hinges, door springs, swing-centres, locks, door furniture, sash and shutter fastenings, hooks, knobs, latches, &c.

There are many other articles of hardware which are included under the term Ironmongery, but here we have only to deal with those which are fixed by the joiner in order to complete his work in a building.

202. NAILS are small strips of iron or other hard metal used for the purpose of either holding pieces of wood together, or of attaching articles of metal to the wood. Nails are always driven in by means of a hammer, and consist of two parts, namely, the *head* and the *shank*. The *shank* is the long slip of metal, generally pointed at one end which enters the wood and is

held therein by the forces of cohesion and friction ; the *head* is the broadest part, upon which the hammer strikes when driving the nail. Nails are various in form, and receive different names according to the uses for which they are intended, or the shape given to their heads or shanks. They are sold either by the thousand (per M.), which is generally about 900 nails, or else according to weight (per cwt.) which is the most common mode.

Iron Nails are of three distinct kinds, namely: 1. Wrought nails, which are made entirely by hand; 2. Machine-made nails, which are either cut or forged by machinery; 3. Cast nails, which are, as their name implies, formed of iron cast in a mould. Each of these varieties has its especial value according to the requirements of the joiner, some parts of his work requiring one sort of nail, and some another. The machine-made nails are those which are mostly in use, owing to their being cheaper than those made by hand, and in most cases equally well adapted for the purposes of joinery. There are, however, some parts of the joiner's work in which the other varieties of nails are employed.

WROUGHT-IRON NAILS.—The nails under this denomination are made by hand from slips of metal hammered out to the required shape upon an anvil. *Tacks* are a small kind of hand-made nails with flat heads and sharp points, and are from $\frac{3}{8}$ths to $\frac{3}{4}$ths of an inch in length; they are often *tinned* over by being dipped in a bath of moulten tin to preserve them; those which are not tinned are subjected to a process called *blueing*, which partly protects them from rusting. *Clouts* are hand-made nails with rounded and pointed shank and large flat circular head; they are used for fixing iron-work upon wood, and vary from 1 inch to 6 inches in length. *Brads* are tapering slips of iron, blunt-

pointed, the top being widened out with a slight projection on one side, which answers the purpose of a a head; some brads are made by hand, as the best kind of flooring-brads, used to nail the floor-boards to the joists. Brads are used by the joiner for laying floors, and for fixing skirtings and other fittings to the wood bricks; they are of all sizes, from ½ an inch up to 3 inches, those used for floors being from 2 to 3 inches in length, according to the thickness of the boards. *Rose* nails are sometimes made by hand and have a flat-sided or wedge-shaped shank, with a chisel-point and a rose-shaped head; they are used for driving into hard woods, brickwork, &c., and vary in length from 1½ inches to 3 inches. *Spikes,* or large spiked nails, are usually hand-made, and are used by the carpenter for fixing the timbers of roofs, floors, and partitions, or as *deck* nails for nailing plank floors to the joists; they are usually from 5 to 7 inches long. *Holdfasts* and *wall-hooks* are large nails for driving into walls, in order to hold woodwork thereto; the former are flattened out at the top, and have a hole drilled therein for a small clout nail to be driven into into the woodwork.

Machine-made Nails.—By far the largest quantity of nails in use are made by help of machinery, which has cheapened them to a very great extent. The machines for nail-making vary considerably, according to the kind of nail to be produced, some nails being cut and others forged or wrought by the machine. *Rose* nails, which have been described above, are largely made by machinery. These are not cut, but forged, and are harder and stronger than those forged by hand; consequently they are better adapted for driving into hard woods, brick or stone walls, and wherever there is great resistance to be encountered. *Brads* are also

generally machine-made; they are rougher than those made by hand, but for most purposes of the joiner the cut brads answer equally as well as the more expensive hand-wrought nails. *Clasp* nails are made with sharp points and arrow-shaped heads for clasping the wood; they are cut by machinery, and much used by the joiner for fixing his work. Clasp nails are designated threepenny, fourpenny, sixpenny, eightpenny, tenpenny, &c., according to their weight per M; one thousand of the first weighing 2 lbs., of the second 3 lbs., of the third 5 lbs., of the fourth 7 lbs., of the fifth 10 lbs., and so on. *Lath* nails, used by plasterers to attach their laths to the joists and quarters, are made with flat heads, and are about 1 inch in length; they are often cut by machinery. *Brass-headed* nails have a wrought-iron shank with sharp point, and a rounded or flat head of brass, sometimes of an ornamental character, the heads always being intended to be seen in the work to which they are fixed; they vary in length from ½ an inch to 3 inches.

Cast-iron Nails.—These are generally very rough in the shank, but on that account they afford a good hold to the material into which they are driven. Since the extensive introduction of machinery into the manufacture of nails, cast nails have been generally superseded by cut nails. *Lath* nails of the cheapest kind are cast, but would seem to be more liable to split the laths than the cut nails. *Wall* nails, used by gardeners for training plants against brick walls, are of cast-iron.

Galvanizing is a process employed for preserving iron nails from rusting by dipping them in a bath of melted zinc; nails, spikes, and holdfasts which are exposed to damp should undergo this process, otherwise they will rapidly decay, and become useless for the purpose they are intended to fulfil.

Gilt-head nails are small flat-headed nails, having a wash of gold on the top, and are used for fittings of an ornamental character.

Brass nails are small tacks having both head and shank of brass, and are used for fixing the escutcheons and finger-plates on inside doors.

Lead-headed nails are clouts having the heads dipped in lead, and are used for driving into lead on roofs.

Copper and Zinc nails are used chiefly by slaters for fixing slates to the battens of a roof. Copper nails are also used to nail down the edge of lead when used as a lining to cisterns, or as a covering to wooden stairs. They have flat heads, like a clout nail, and are blunt pointed; they vary in length from $\frac{3}{4}$ths of an inch to 2 inches.

203. Screws are small cylinders of iron having a spiral thread cut upon them. Like nails, they consist of two parts, the shank and head; the former is a long cylinder of small diameter as compared with the length, having the spiral thread above mentioned cut upon it from the lowest end, and extending about half way up towards the head. The *head*, which is circular on plan, and either flat or spherical, has a groove cut across along a diameter of the circle, for the purpose of inserting the edge of the screw-driver, by which the screw is driven into the hole previously made for it in the wood, by turning from left to right, or in the direction of motion of the hands of a watch; when the screw has to be drawn out, the turning must be in the direction opposite to that in which the hands of a watch move. Nearly all ironmongery, such as hinges, bolts, locks, &c., are fixed on the woodwork with screws, flat-headed screws being used for hinges, and spherical-headed for bolts, locks, &c. Screws are of all lengths from $\frac{1}{2}$ an inch up to 4 inches.

Gilt-head screws are those which have a wash of gold on the top of the head, and are used for fixing brass work, as hinges, sash fastenings, &c.

Some screws are made with square heads, and have a nut, in which a female screw has been tapped, working upon the end. These are used when any piece of ironmongery has to be secured on the opposite side of the woodwork to which it is attached, and the nut enables the joiner to screw it up with any degree of tightness, as in fixing door-knockers, plates, knobs, &c. Brass and iron knobs, knockers, and door-plates, are usually fixed upon doors, drawers, &c., with a nut and screw in the manner above described. Brass *dresser-hooks*, for fixing upon the edges of shelves, &c., have an iron shank with a screw tapped upon it for driving into the wood.

Thumbscrew is an iron screw with a brass head made flat to be held by the thumb and finger, and is driven into a nut or female screw fixed in a shutter or sash.

204. HINGES are metal fastenings by which doors, shutters, flaps, lids, &c., are hung to fixed frames or stiles, and upon which they turn in opening and closing. There are many kinds of hinges; but the main principle is the same in all, namely, that of being in two distinct parts, one fixed and the other turning upon it by means of a pin passing through the *knuckle* or projecting part of the hinge. The *knuckle* consists of two equal and hollow cylinders, each of which is attached to a flat piece or *strap* in which there are screw-holes for fixing, indented one into the other so as to form one complete cylinder, made up of three, four, or five pieces, all of which are connected by means of a cylindrical pin passing down the *axis of the hinge* Doors, &c., are always hung with two or more hinges, whose axis must be fixed in the same straight line, which is called the *line of the hinges.*

Butt hinges are those in which the knuckle only is visible when the door or shutter to which they are attached is closed; the straps being screwed into sinkings cut at the edge of the door and of the hanging stile, frame, or lining to which it is hung. If a door has to be hung so as to clear a projection when thrown back, *projecting* butts are used, in which the knuckle has a considerable projection from the face of the door. Butt hinges are made of cast and wrought iron, and also of brass. The sizes vary from 1 inch in height up to 5 inches.

Rising butt hinges are those in which the knuckles are cut so that the parts work upon each other in a spiral direction, and lift the door as it opens, so as to clear a thick carpet; doors hung with these hinges will fall-to of their own accord when released. These hinges are made of both iron and brass, from 3 to 6 inches in height.

Back-flap hinges are used for hanging the back-flaps of shutters, and are very similar in construction to butts, only having wider straps, which are screwed to the face of the shutters instead of the edge, as is done with butts, by which means the shutters when opened out are all in the same plane, and when closed in their boxings can fall flat against each other.

Cross-garnets are made in the form of the letter ⊣, the cross piece being screwed to the fixed frame, and the strap at right angles to it screwed to the face of the door or flap, so that the whole hinge is visible when the door is closed. They are made of iron, and are sometimes japanned.

H and **H-L** hinges, of brass or iron, are somewhat similar to cross-garnets, and of the form of the letters which designate them; *Parliament* hinges are of this form, and used when it is required to hang a shutter

outside a window, so that it shall fall back against the wall when open and clear the reveal.

Gate hinges are made with a long strap of cast or wrought iron, which is bolted or screwed to the rail of the gate, and has a hollow cylinder at the outer end, which turns on a solid iron cylinder fixed to the gate-post; the best are made with a spherical or cup-and-ball bearing, so as to move on each other with as little friction as possible.

Spring hinges are those made to close a door when released from the hand by means of a spring, and are of various forms and descriptions. *Rising* spring hinges are similar to the rising butts, having in addition a coiled spring to bring the door quickly back; these are generally used for room-doors.

Spring-centres are mostly used for swing-doors of public buildings, shops, banks, offices, &c.; these are fixed at top and bottom of the door, which turns upon them as pivots, the bottom pivot being connected with a powerful spring in a brass case sunk flush with the floor; with these the door can be made to swing one way or two.

Door-springs are attached to the side of a door which has been hung in the usual manner with butts. The spring is contained in a small cylinder fixed on the frame or hanging stile, to which is attached a movable iron rod, having a small wheel at the outer end, which runs on a slip of iron let into the door-rail; the spring presses the iron rod firmly against the door, so as to close it when it has been opened.

Vulcanized india-rubber springs are also used for the same purpose; they are stretched by the opening of the door, and their elasticity enables them to pull the door to when released.

205. LOCKS are fastenings or spring bolts attached

to doors, &c., in order to prevent them from being opened except by means of the *keys* which are adapted to them.

There is an endless variety of lock in use, but we shall only notice those especially adapted to joiners' work, referring the reader for fuller information on the subject to the "Treatise on Locks," by C. Tomlinson (No. 83** in the Rudimentary series). Locks are distinguished according to the nature of their internal construction as well as their outside appearance, and the uses to which they are applied.

They consist in general of a case formed of iron, brass, or wood, which contains a bolt to be shot into a staple or box, and it is the shooting of this bolt which forms the whole mechanism of the lock. There is a hole on one or both sides of the lock-case into which the key is inserted, the turning of which upon a pivot or small cylinder moves the bolt backwards or forwards. In order that no other key but the right one may be used to shoot the bolt, a series of thin projections called *wards*, in the form of concentric circles, are fixed round the pivot upon which the key turns; the key having clefts cut in the *bitt* or flat part to correspond with the wards. It is evident that if any key which has not these clefts is introduced into the lock, it cannot be turned on account of the projection of the wards.

Master-key is a key which has the bitt so formed that it will turn in the wards of several differently warded locks, so that a person possessing such a key can open any of them, although the key belonging to one will not fit another lock.

Back-spring lock is the commonest description, consisting of a bolt with two notches on the under side, acted on by a spring pressing the notches down upon

a projection, the action of the key being to lift the bolt from one notch to the other.

Tumbler locks are made with levers called *tumblers*, which fall into the bolt and prevent it from being moved until raised by the key.

In ordinary locks there is usually but one tumbler, but in the superior kind there are several, which render the lock more difficult to pick.

Lever locks are similar in principle to tumbler locks, but in the former the tumbler carries a stud which secures the bolt, and in the latter the stud is carried by the bolt and pressed upon by the lever.

There are numerous patented locks of various degrees of complexity and security, which can only be explained in a separate treatise on the subject.

Draw-back lock is one which is fixed on entrance-doors, the bolt being pulled back by the pressure of the hand on a knob placed on the inside of the door, or shot by means of a key passed in from the outside ; the key will also shoot the lock further into the *box* when it is required to double-lock the door. These are sometimes denominated *stock* locks, and vary from 7 to 12 inches in length ; there are other *stock* locks which have no draw-back knob, but are only worked by a key, and have an iron or a wooden case.

Iron-rim lock consists of a japanned iron case, which contains the mechanism, and is screwed on the side of a room-door. This lock has two or three separate bolts, one of which is acted on by a knob turning a spindle, another is shot in the usual way by a key, and the third is a small bolt shot by pressure of the finger ; a lock which has all these bolts is called *three-bolt* lock, and one in which the small bolt is omitted, a *two-bolt* lock. An iron *box* is screwed on to the door jamb, into which the bolts are shot.

Brass-case lock is similar to the above, the case being of brass instead of iron, and the mechanism generally superior in finish.

Mortise lock is one that is enclosed in a thin case of iron with a brass *face-plate*, and is let into a mortise cut in the lock-rail of the door, so that only the face-plate is visible, which is flush with the door edge, and is screwed thereto with brass or gilt head screws. These locks are always used for room-doors of the better class; they are either two or three-bolt.

Dead lock is one which has only a single bolt shot by a key, as those used for cupboards, drawers, &c. Locks are denominated *right* or *left* handed according as they are made to be fixed on the right or left edge of the door looked at from the outside.

Furniture is the term applied to the knobs fitted to room-doors for turning the spindle which shoots or draws back the bolt of the lock; these are made of brass, china, glass, ebony, oak, or other material, and are fitted to a square spindle passing through the door. The common mode of fixing the knobs to the spindle is by a screw through the neck of the knob into a notch or hole in the spindle; as, however, from constant use this screw gets loose, several better methods of attaching the knobs have been invented.

Escutcheon is a piece of metal which is fixed round the keyhole of a door, and serves as a guide to the entrance of the key. It is of various forms, but commonly consists of a flat plate with a hole for the key in the middle, which is nailed or screwed to the woodwork. A *thread* escutcheon is a narrow slip of metal which fits exactly into the keyhole. Escutcheons are often provided with a drop or cover to prevent dust from entering the lock.

Latch is a simple form of lock, intended merely for

keeping a door closed, but so that it can be opened at pleasure on either side. There are several varieties, as the *thumb,* the *Norfolk* and the *Suffolk* latch, which are opened by means of a lever lifting up the latch from the catch into which it falls by its own weight when the door is closed. There is also the *bow* latch, which is lifted by a knob and spindle, and pressed down by a spring; the mortise latch is similar to a mortise lock, but with only one bolt moved by a knob and spindle. *Turnbuckle* is a simple form of latch for closet-doors, being a thin slip of iron placed on the inside of the door and turned by a brass knob on the outside.

206. Bolts may be considered as locks of the simplest form, being rods of iron shot backwards and forwards by hand. *Barrel* bolts have the rod working in a hollow cylinder of iron or brass by means of a projecting knob, which shoots them into a *staple* fixed to the door-frame. *Flush* bolts are those in which the bolt works at the back of a flat plate of metal, which is let in so as to be flush with the face or edge of the door.

Bolts for coach-house and other large folding doors are fitted with a spring to prevent them from falling down by their own weight when shot vertically, and have a long handle attached so as to come within reach of a man's hand.

207. Window-fittings.—Hung sashes are usually secured by a spring latch fixed on the bottom rail of the upper sash and turning on a pivot so as to pass under a hook on the top rail of the lower sash. There are several varieties of these fastenings, but all are similar in principle. Another mode of securing sashes is by driving a *thumbscrew* through the two meeting rails. Heavy lifting sashes are provided with brass *lifts* screwed to the bottom rail of the lower sash, so as to form a hold for the fingers.

Casements are secured either by a small latch turning on a pivot and dropping into a hook fixed on the frame, or, if hung folding in two leaves, the best kind are fitted with an *Espagnolette* bolt, consisting of a vertical rod the whole height of the casement, which is fixed at the meeting edge of one fold and hooked at top and bottom into the other, being worked by means of a handle at the middle of its height. There is also a *weather-tight fastening* for casements, consisting of a brass tongue let into the edge of one fold and shooting into a groove in the edge of the other.

Lifting shutters are provided with *sunk flush rings* let into the top edge, for the purpose of raising them, and are secured by means of a thumbscrew passing through both top and bottom shutter. Folding shutters are secured with a *locking bar* of wrought iron fastened on one fold, and latched upon a knob or spring catch screwed to the other fold.

Axle-pulleys are fixed in the cases of lifting sashes and shutters for the cords to pass over; they consist of an iron or brass grooved wheel working on an axle in an iron or brass frame or face-plate.

Cabin-hook is a fastening used for securing a casement when open, so as to prevent it from falling to. It consists of a simple hook and eye, one part screwed to the frame and the other to the casement. Cabin-hooks are also employed for holding open doors or flaps.

Casements are often held open by means of a *stay*, consisting of a flat rod of brass or iron passing through a fixed eye, having holes drilled at short intervals, into which a pin or screw is dropped, so that the casement can be fixed open at any required angle. The bar is also sometimes made to hook on by one of the holes to a stub fixed on the window-sill.

208. Miscellaneous. There are several other articles of ironmongery which the joiner has to fix upon a building, of which we shall enumerate a few. Brass and japanned iron *buttons* are fixed upon closet doors by means of a screw passing through the middle, but left sufficiently loose to allow of their being easily turned with the finger and thumb. *Knobs* of brass, iron, china, mahogany and other hard woods, are fixed on doors or drawers by means of an iron or wooden screw, and sometimes with a *nut* screwed on the inside to prevent them from drawing out of the wood. Hat and cloak *pins* are made of brass, japanned iron, or wood; those of metal being either double or single, and screwed by means of a plate at the base to a wooden rail; pins of wood are screwed into the rail by a screw tapped on the end. *Stubs* and *plates* are fixed upon the bottom of movable shop shutters, the *stub* being a projection of iron which fits into a hole in the *plate*. Brass *eyes* are fixed at the junction of the treads and risers of a staircase, through which the brass rods are passed for keeping the carpet in its place. *Flush-rings* are those which are let into a mortise cut in a piece of joinery, and have the top of the ring *flush* with its surface; when required to be used the ring is drawn out by the finger and thumb. *Flush-lifts* are handles let into wood framing so as to give a hold for the ends of the fingers in raising it. *Meat-hooks* are large wrought-iron hooks, generally tinned over, having a screw on one end, which is driven into a beam in the ceiling of a larder.

Blind-rollers, for raising and lowering inside blinds, are worked in various ways; the commonest method is by a pulley made of hard wood or brass screwed to one end of the roller, which turns on pivots in either brackets or thimbles; over the pulley a cord is passed

which also goes round a small pulley on a *rack* below, by which means the cord can be tightened at pleasure, and by pulling the cord the roller turned, and the blind which is fixed thereto raised or lowered. *Spring-rollers* are those which have a coiling spring in a box attached to one end of the roller, and by pulling a cord loosely attached to a lever the spring is released and the blind coils itself up.

Chain and barrel fastenings are fixed on outer doors so as to allow of them being opened only a few inches if required; the chain is screwed by a plate to the door frame, and a long barrel having a slit cut along it is fixed on the door. Into this is inserted a knob attached to one end of the chain, which slides in the barrel, and cannot be drawn out except at the end at which it was inserted, and when the door is quite closed. *Knockers* for outer doors are of iron or brass, and are screwed on by means of nuts attached on the inside to screws passed through the door. *Door-plates* are fastened on doors with screws and nuts in the same way as knockers are fixed, the screws being soldered to the back of the plate.

Brass *picture-rods* are fixed round the top of rooms in first-class houses for the purpose of hanging pictures thereto by means of hooks moving loosely along the rods, and prevent the necessity of injuring the walls by driving in nails. These rods are held by brass brackets screwed into a deal ground previously fixed in the wall before being plastered, so that its face is flush with the plaster, and is covered over with the paper hangings.

Brackets for supporting shelves are made of cast or wrought iron and brass; they are screwed to the underside of the shelves, and also into a plug or ground of wood let into the wall.

Finger-plates are fixed above and below the lock of a room door, to prevent the paint from being soiled or rubbed off by the hand in opening and closing it. They are made of an ornamental character in brass, china, or glass, and are fixed by means of small nails or screws driven through holes made in their edges.

Sash-lines, for hanging sashes or shutters, are usually made of flax or hemp twisted in a peculiar manner, and generally known as *patent* line. Leather and copper lines are sometimes used, and also brass chains where the sashes are very heavy.

APPENDIX.

Experiments made in the Royal Arsenal, by T. Laslett.*

Kind of Wood	Spec. Grav.	Modulus of Elasticity E.	Tensile Strength per sq. in. Section.	Crushing Strength per sq. in. Section.	Value of a, p. 117.	Value of c, p. 123.
		lbs	lbs.	lbs.		
Ash, English . .	·750	2,292,400	3,780	6,965	·0075	754
Ditto, Canadian .	·588	1,375,920	5,600	5,495	·0125	558
Cedar (Cuba) . .	·469	1,798,840	2,870	4,480	·0096	490
Elm, English . .	·642	1,003,280	5,460	5,786	·0172	344
Ditto, Canadian .	·748	2,474,200	9,180	8,586	·0171	805
Fir, Dantzic. . .	·756	1,737,570	3,230	6,948	·0070	767
Ditto, Riga . . .	·570	3,009,680	4,050	5,248	·0051	525
Greenheart . . .	1·141	1,747,520	8,820	14,411	·0098	1166
Larch, Russian . .	·649	2,596,520	4,200	5,815	·0067	548
Mahogany, Spanish	·765	3,084,120	3,790	6,415	·0056	749
Ditto, Honduras .	·659	1,970,200	3,000	6,395	·0088	702
Oak, African . .	·993	1,641,720	7,050	10,002	·0105	970
Ditto, American, white	·969	2,144,600	7,020	6,451	·0080	703
Ditto, ditto, live .	·742	2,812,920	3,830	5,991	·0062	632
Ditto, Dutch . .	—	1,106,200	—	—	·0156	576
Ditto, Dantzic . .	·838	—	—	7,558	—	414
Ditto, English (seasoned) . .	·740	1,545,600	7,570	7,475	·0112	705
Ditto, French . .	·977	2,480,880	8,100	7,945	·0070	747
Ditto, Italian . .	1·041	1,527,740	—	5,459	·0113	737
Ditto, Spanish . .	—	956,760	—	—	·0181	491
Pine, pitch . . .	·659	3,020,940	4,670	6,462	·0057	769
Ditto, red, Canada	·353	2,355,600	2,710	5,600	·0073	572
Ditto, yellow, ditto	·471	1,236,960 to 3,611,800	2,030	4,234	·0140 to ·0048	471
Spruce, Canada .	·484	3,087,200	3,930	4,852	·0056	586
Teak, Indian . .	·777	2,123,880	3,300	5,733	·0081	768

* "Timber and Timber Trees."

STRENGTH OF AMERICAN TIMBER.*

Kind of Wood.	Spec Grav.	Modulus of Elasticity, E.	Value of a, p. 117.	Value of c, p. 123.
		lbs.		
Ash, white, unseasoned	·781	1,928,930	·0089	646
Ditto, ditto	·698	1,764,766	·0097	653
Ditto, partly seasoned	·642	1,440,000	·0120	680
Beech, white, unseasoned	·718	1,423,060	·0122	453
Ditto, red, ditto	·821	1,555,200	·0111	530
Ditto, ditto	·785	1,555,200	·0111	579
Ditto, seasoned	·710	1,623,273	·0107	650
Birch, black, unseasoned	·781	1,105,920	·0159	462
Ditto, yellow, ditto	·756	1,152,000	·0150	445
Ditto, dry	·679	2,073,600	·0083	842
Cedar, white (*arbor vitæ*)	·355	552,960	·0313	255
Elm (rock) unseasoned	·746	1,105,920	·0159	672
Ditto, seasoned	·749	1,809,320	·0095	874
Hickory, white	·836	1,152,000	·0150	735
Oak, white, unseasoned	·918	1,229,900	·0140	515
Ditto, ditto	1·034	1,120,870	·0154	447
Ditto (heart) ditto	·951	1,382,400	·0125	500
Ditto, ditto	·794	1,382,400	·0125	574
Ditto, ditto, seasoned	·775	1,536,000	·0112	702
Ditto, black, unseasoned	·964	1,234,300	·0140	555
Pine, red, ditto	·506	1,102,000	·0157	420
Spruce, black, ditto	·670	1,254,000	·0138	370
Ditto, ditto	·875	977,554	·0177	321

* From Experiments by Lieutenant Dennison, R.E., Trans. Inst. Civ. Eng., vol. ii.

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THE END.